

MANUFACTURING OPERATIONS MANAGEMENT - THE SMART BACKBONE OF INDUSTRY 4.0

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Abstract: Industry 4.0 offers an unprecedented opportunity for transformational success, but companies must have plant floor software that is ready for that journey. The fact that Industry 4.0 is already predicted means companies can prepare themselves now. This paper helped companies understand what they need to drive manufacturing in an IIoT world and the new role of manufacturing operations in the enterprise. It also discussed what Smart Manufacturing means and why companies should start the journey now, actions executives should take to address the convergence of IT and automation, and key criteria for selecting a MOM partner to support next-generation business solutions.

KEYWORDS: INDUSTRY 4.0, IIOT, OPC UA, MOM, MES, FCS, SCHEDULING, CMMS, ISA 95, IEC 62264

1. Introduction

The Industry 4.0 vision of decentralized, autonomous networks of smart products and automated equipment collaborating in smart supply chains is the direction manufacturing industries must move to achieve intelligent, high-performance, resource efficient and fully predictive manufacturing. The subject of this paper is the transformation of Manufacturing IT in order to handle this new complex environment successfully. Industry 4.0 shapes a future of agile, affordable manufacturing fueled by technology enablers such as the Internet of Things (IoT), Additive Manufacturing (3D printing), Augmented Reality, Cloud Computing, Mobile Devices, Autonomous Robots and Big Data Analytics (Figure 1)[9]. That future reality actually does have the potential to change the process of manufacturing. It's a disruptive change of how companies and supply chains work, what people and software applications do, and what customers can expect and when. That does not mean all the processes, equipment, IT systems, and procedures a company uses today will disappear. They need to prepare for the following transformations:

- Distributed Manufacturing - from centralized to decentralized decisions and control
- Autonomous Machines (robots) - from people directing or even doing much of the operations work to automated intelligent mechanisms capable of acting independently
- Vertical Integration - from isolated systems at each level (work centers, production lines and units, plants, enterprises) to vertically integrated information flows that enable full business processes. That includes IT/automation convergence of information technology (IT) systems used for data-centric computing with automation technology systems traditionally associated with industrial control systems (ICS) such as supervisory control and data acquisition (SCADA).
- Horizontal Integration - from separate systems in each department and organization in the supply chain to horizontally integrated information flows among everyone in the organization and extended supply chain
- Simulation – from somehow organized to fully predictive processes, which could be readily tuned to the best performance with the respect to specific but fast-changing requirements faced by complex manufacturing businesses
- Augmented Reality - from drawings, instructions and manuals to context-sensitive interaction between people and technology.
- Reliability Centered Maintenance - from reactive maintenance of the assets and tools to smart predictive, condition-based one in the environment of big data.

- Mobile - from large companies and particular types of processes being connected to the widespread democratization of connectivity, mobility and location-sensitive technologies
- Cloud Computing - from on-premises to cloud-based, service oriented computing
- Big Data Analytics - from limited and localized analytics to advanced plant-wide analytics, both real-time and offline

For most manufacturing companies, a disruptive approach to implementing new and thus unknown technologies is rather risky. Industry 4.0 technologies are at the heart of most manufacturing processes and influence critical steps within the value chain. The cost of production downtime per day is high, and thus manufacturing companies will carefully weigh the benefits of introducing new technologies against possible risks to process reliability. In addition, many companies had some concerns around having the right skills to capitalize on Industry 4.0. Digitalization skills are critical. The younger people coming through are digital natives but there are generations of existing workers who will need to rapidly reskill and retool. As a result, companies approach fundamental disruptions with caution, so that change will be rather incremental.



Figure 1. Industry 4.0 enablers [4]

All these transformations could be challenging to fully understand Industry 4.0 and what it will mean to a company and to its manufacturing IT systems. The convergence of all of them is truly disruptive, and opens up entirely new opportunities and challenges.

Our goal with this paper is to go beyond the vision and the technology hype and propose an approach for the gradual migration to Industry 4.0. Our approach envisions a seamless, connected factory where Cyber-Physical Systems (CPS) communicate and collaborate with each other, but also, at a new level, with customers and employees. The backbone of such complex software and hardware integration will be provided through a Manufacturing Operations Management (MOM) systems. [4]

2. Basic concepts of MOM/MES for Industry 4.0

Successful manufacturing, particularly as it has gone global, has relied heavily on Manufacturing Execution Systems (MES) – also sometimes called Manufacturing Operations Management (MOM) [8]. This multi-faceted software for production plants has been a pivotal enabler for the performance, quality and agility manufacturing leaders have achieved.

There is an ongoing discussions about the use of the term manufacturing execution system (MES) vs. manufacturing operations management (MOM) to describe the type of software solutions used in production operations. We would like to clarify our position in this dispute. For us, MES stands for computerized systems used in manufacturing, to guide, track and document the transformation of a consumed to produced materials at one work place (process line/unit) including data exchange with automation layer (SCADA, DCS, PLC, CNC). MOM systems, extend the functionality of a MES to cover the whole manufacturing process in an area, including Final Capacity Scheduling (FCS), Workflow Management (digitalize manual work), Maintenance Management (CMMS, EAM), Quality Management (QMS, LIMS) and Warehouse Operations (WMS), etc..

We expect MOM will continue to play an essential role in the manufacturing enterprise's IT landscape because it sits at the critical point where revenue-generating products come into being. MOM already handles rapidly flowing streams of disparate unstructured and structured data and turns it into useful, targeted information in a near real-time fashion. The upcoming Cyber-Physical Systems (CPS) and Cyber-Physical Production Systems (CPPS) data will require this and more.

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

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

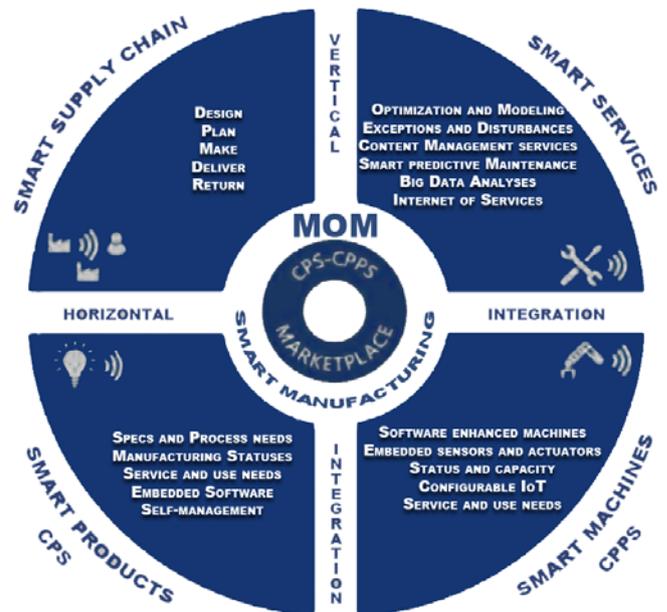


Figure 2. MOM/MES plays a central role in Industry 4.0

The primary functions of MOM are a critical foundation around which manufacturers can build the Industry 4.0 application structure. Today, MOM provides critical information both within the production environment and to the supply chain, customer service, product development and management teams. Industry 4.0 will not be fully implemented overnight, so there will be a transition period.

Over the longer term in Industry 4.0 situations, MOM will play several roles. Figure 2 shows a simplified concept of this:

- Sit at the center of the smart supply chain
- Sit at the center of the product lifecycle - an end-to-end information flow, a “digital thread” that runs through the entire product lifecycle as its digital representation.
- Be the essential coordinator for both the horizontal and vertical integration of Industry 4.0
- Prepare online Final Capacity Schedules based on real-time capacity reported by the CPPS and the actual statuses from CPS. Implement advance optimization algorithms and supporting emergency re-planning in case of incidents
- Supervise and coordinate the manufacturing workflow
- Monitor, and as needed, coordinate the CPS-CPPS marketplace and incorporate CPS and CPPS data into off-line compliance and quality activities
- Act as the stand-in for any products, materials, or equipment that are not CPS enabled
- Be the place to collect and store Big Data related to the manufacturing process
- Provide operational KPIs and enable complex statistical analyses (SPC)
- Manage operations related to smart predictive and condition-based maintenance
- Deliver aggregated information for customer service and other ecosystem activities
- Serve as an Intranet Content Management System (CMS) for facilitate true collaboration inside a plant

3. Main characteristics of MOM for Industry 4.0

MOM is a critical element in the manufacturing IT landscape and therefore it requires a completely new generation of MOM

systems to cope with the new challenges created by Industry 4.0 (see Figure 2). The following are the main characteristics MOM needs to support Industry 4.0 effectively.

Decentralization

Industry 4.0 is inherently a decentralized system, with intelligence in independent entities. Smart materials and products (CPS) are service consumers and smart equipment and plants (CPPS) are service providers. CPS and CPPS are not physically coupled; rather, a dispatching operation delivers logical binding between a material to be processed and a resource to process the material.

Since each product in the Industry 4.0 vision may be unique, it will be very difficult to centralize or optimize shop floor operations in the traditional way. Managing the end-to-end information flow will facilitate information sharing with suppliers and distributors, enabling further operational effectiveness through approaches such as real-time supply chain optimization and data-driven demand prediction, which will reduce inventory costs and improve service levels due to a better match between supply and demand. In asset-heavy manufacturing businesses (such as those in the automotive industry), remote monitoring and predictive maintenance will play an important role to improve asset utilization by decreasing unscheduled downtime. It facilitates maintenance scheduling, work execution, and material availability processes. In energy intensive manufacturing, the real-time scheduling and optimization of machine times will decrease the energy costs. The future MOM systems will extend the production planning and control area to include energy-oriented order planning which, in conjunction with smart grids, will continue to permit flexible energy and cost efficient planning even in the face of rising energy costs.

All of the above will increase the demand for a near real-time fast optimisation algorithms for Final Capacity Scheduling and Re-Scheduling of the production sequences. The extension of classical control principles to include autonomous goal redefinition makes it possible to establish artificial intelligence in technical systems. In conjunction with the availability of real time information, this paves the way for the creation of robust and at the same time flexible production systems even in highly dynamic Industry 4.0 environments.

The dynamic marketplace of CPS and CPPS means that rather than hold a single unifying model, the MOM needs context resolution possibilities. This allows a product that requires a certain service at a certain step to combine the flow of its product category to be adapted, or unique to its specific context. Going one step further, the smart product may hold the recipe (set points) needed at a given processing step. When negotiating with the smart resource, it will transfer the recipe to the resource so that it can perform its unique transformation process. So the CPS and CPPS have their own intelligence. As an example, a smart product CPS knows its state, its position, its history, its target product and its flow alternatives. Likewise, a smart resource or CPPS will hold information about its state, its history, its maintenance plan, its capacity, its range of possible configurations and setups, etc. What this means is that a smart product or CPS has the capability to identify itself, providing its position and state to a physically centralized system. MOM decentralization needs to be mainly logical. With cloud computing, it's such a system could not be considered physically centralized. What is critical is that the logical decentralization must exist. So the MOM may be a loosely connect applications (apps) that acts decentralized with agents or objects representing the shop floor entities and are connected through web services.

A good starting point for defining the objects and the logical separation is the existing standard IEC/ISO 62264 (ANSI/ISA 95) "Enterprise-Control System Integration".

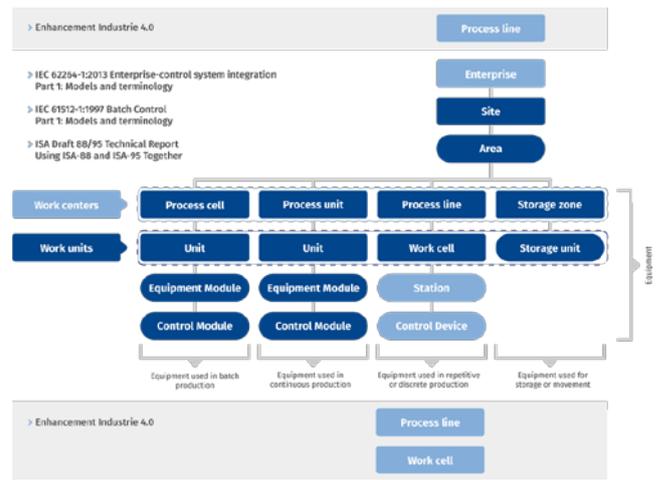


Figure 3. Industry 4.0 CPPS Equipment Hierarchy

Vertical integration

MOM has traditionally resides in the space between administrative IT systems (ERP, SCM, CRM, etc.) and the automation layer (SCADA, PLC, DCS, CNC, etc.). This vertical integration is an enabler for the orchestration of everyday business processes that may be simple or complex but nearly always require multiple layers and groups to be involved. Business processes for compliance, quality, maintenance, logistics, engineering, sales or operations all have components inside the plant as well as others that reside beyond the factory that are crucial to a business process being executed effectively.

In Industry 4.0, CPS and CPPS communications create new data flows to integrate. For example, a CPS or smart product may know that it needs to stop a lot or only part of it (sub-lot) and collect a measurement process parameters or other related information such as downtimes, quality checks, etc. The layer above then specifies and checks whether the outcome is correct. This is where statistical process control (SPC) rules reside, and if it's not within limits, it might open a corrective and preventive action (CAPA). All of that activity will be in a layer above the CPS in controls of MOM.

Within the plant, the MOM will need to aggregate and put these additional data flows into context. Vertical integration of these autonomous entities is critical as they could otherwise make decisions independent of the rules and best practices for the factory or company. MOM providers must continue to expand the product capabilities to ensure that all plant activities are visible, coordinated, managed and accurately measured. Only then can the enterprise systems respond effectively. Thus optimum parameters, process conditions and process strategies for increasing the efficiency of manufacturing and product quality can ultimately be derived from neural networks, decision trees or correlation analyses and feedback into the system. The technology database and the subsequent analysis operation permit end-to-end data acquisition, analysis of production data throughout the process chain and the derivation of optimum process settings.

Horizontal integration

In the Industry 4.0 final report, horizontal integration focuses on supply chain status communication among facilities and trading partners. Horizontal integration enables the smart supply chain or network to be transparent so status is always visible. What horizontal integration requires is service oriented ways of alerting the rest of the information system to the information available.

However, that is not likely to all come from the CPS and CPPS directly. In Industry 4.0, the MOM must be truly modular and interoperable so that all functions or services can be consumed by CPS smart materials, CPPS smart equipment or any other shop floor entity. As an example, a typical maintenance management process, often centralized, could consist of a series of services that each

piece of equipment might use. Horizontal integration may extend from the internal maintenance team to the external subcontractors. With extensive outsourcing and supplier base, this is a vision these industries could benefit from greatly.

Connectivity, sensing and mobile

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

Industry 4.0 is creating a true democratization of such connectivity, allowing it to be widespread in manufacturing facilities of different sophistication levels. Three elements contribute:

- The IoT, in the industrial world called IIoT (Industrial Internet of Things) translates into very low cost hardware (RFID, etc.) and lean OS (such as Windows 10 IoT running on a Raspberry Pi), allowing true connectivity with equipment not requiring heavy systems and interfaces.
- Increasingly affordable passive identification and location tags allow all shop floor resources (CPS and CPPS) to hold their positioning coordinates. The MOM needs logically autonomous entities to store this location data and show it in real-time in interactive maps.
- The traditional automation pyramid with central PLC or SCADA will be replaced by an OPC UA based CPS network.

Quickly changing products and services resulting from a shift in customer expectations require agile software development methods with daily or weekly release cycles. As these short release cycles are not only often a challenge for established IT processes, but also for existing IT and data infrastructure, companies should make the following preparations:

Introduce a parallel fast-speed IT and data infrastructure. Since not all processes require quick release cycles, a parallel fast-speed architecture should be introduced alongside the transactional architecture. The fast-speed architecture requires manifold interfaces with the transactional architecture, the connected devices on the shop floor and with customers, supplier systems, and others. Companies should make use of emerging data and interface standards to minimize the effort required for the continuous integration of new data sources.

On the operational side of MOM software, connectivity and mobile combined will allow more adaptable interfaces. MOM will consist of different apps, making a reality the vision of getting to a piece of equipment, downloading and later using an app specifically built to operate that equipment. An intelligent web-based portal accommodating this apps and seamlessly connects users, teams and knowledge so that people can take advantage of relevant information across business processes will help them to work more efficiently. The transition to configurable Enterprise Content Management Systems (eCMS) is the obvious path ahead for a MOM systems of the future.

The same combination of mobile devices with the increase in reliable and inexpensive positioning systems will also allow the representation of real time positioning in 3D maps, opening the door to augmented reality scenarios. A person with augmented reality can walk around and get immediate identification of items, and be pointed to their location. Maintenance operations can benefit particularly.

On one side, equipment integration, typically done with well-defined and complex interfaces, will need to be complemented with connectivity. Sensors, actuators or other equipment come into play not requiring heavy systems and interfaces. On the other hand, on

the operational front, combined connectivity and mobile will enable more adaptable interfaces. This mean that MOM will consist of different apps, allowing you to get the equipment, downloading, and using an app specifically built to operate that equipment.

Cloud computing and advanced analysis

The Smart Factory vision of Industry 4.0 requires achieving a holistic view of manufacturing operations. Clearly this can only happen by integrating data from several different sources rapidly and flexibly. This suggests the MOM of the future must also leverage cloud computing and advanced analytics.

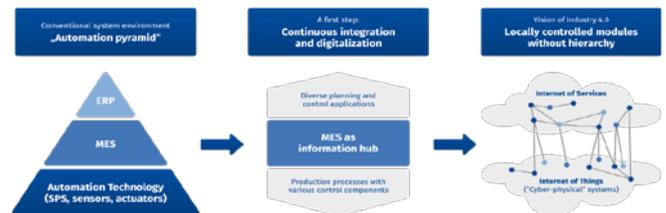


Figure 4. Transformation vision by Simestic

Considering a hybrid cloud strategy of integrating private and public cloud services is the smart choice for a MOM solution. A private cloud is the best option of providing security to sensitive data while satisfying regulatory requirements on data storage, and a public cloud is the preferred way of cutting down the costs of scaling operations of non-sensitive big data. One hybrid strategy is to sign up with a single cloud provider that provides both private and public cloud services. An alternative is to sign up separately with a private cloud service provider and a public cloud service provider. The third option is to set up a private cloud service in-house, on-premises and then sign up with a public cloud service provider.

While many MOM have manufacturing intelligence components today, this must expand to better accommodate the diversity and volume of big data. Both CPS and CPPS will generate huge amounts of data, which needs to be stored and processed. Advanced analytics are then needed to fully understand the performance of the manufacturing processes, quality of products and supply chain optimization. Analytics will also help by identifying inefficiencies based on historical data and pointing staff to corrective or preventive actions for those areas.

Future MOM must accommodate both:

- Advanced offline analysis using very sophisticated statistical process models. These will need to be both in structured data, generally residing in a relational database or in data warehouse cubes, and in unstructured data, which is very difficult to analyse with traditional tools.
- “Real-time” analysis to trigger actions in the plant as quickly as possible, even before data is stored. This needs techniques such as “in-memory” and complex event processing. Cloud computing is the obvious infrastructure for the speed and agility suggested by Industry 4.0.

Manufacturing data analysis is an area where some leading manufacturers are already starting to leverage the cloud.

The Industry 4.0 approach is to combine intelligent manufacturing solutions that will target fully predictive processes, which could be readily tuned to the best performance with respect to specific but fast-changing requirements faced by complex manufacturing businesses. [6, 7]

4. Standards

Industry 4.0 and related initiatives recognize that efficiently building self-managing production processes requires open software and communications standards that allow sensors, controllers, people, machines, equipment, logistics systems, and products to

communicate and cooperate with each other directly. Future automation systems must adopt open source multivendor interoperability software application and communication standards similar to those that exist for computers, the Internet, and cell phones. Industry 4.0 demonstrations acknowledge this by leveraging existing standards, including the ISA-88 (IEC/ISO 61512) batch standards, ISA-95 (IEC/ISO 62264) enterprise-control systems integration standards, OPC UA, IEC 6-1131-3, and PLCopen.

The harmonization of standards worldwide recently took another step forward when representatives of the German alliance Platform Industrie 4.0 and the U.S.-based Industrial Internet Consortium met in Zurich, Switzerland, in March 2016 to explore the potential alignment of their two architecture efforts—respectively, the Reference Architecture Model for Industrie 4.0 (RAMI4.0) and the Industrial Internet Reference Architecture (IIRA).

On 6 April 2016, the OPC Foundation and Object Management Group (OMG) announced a collaborative strategy for technical interoperability that encompasses the OPC Unified Architecture (OPC UA) and the OMG Data Distribution Service (DDS) standard.

These are significant cooperative efforts that illustrate maturity in the industrial automation industry. They recognize that manufacturing has worldwide interdependencies requiring common standards and interoperability.

5. MOM4 implementation

Based on the above findings, NearSoft had developed MOM4 solution as a culmination of leveraged technology: distributed application design, object-oriented programming methodologies and multi-tiered Service Oriented Architecture (SOA) and a broad understanding of manufacturing process, applied to the business and integration needs. The MOM4® is based on the international standard IEC 62264 (ANSI/ISA-95) [1,2,3] and is therefore also investment and future proof under the RAMI 4.0 Reference Architecture.

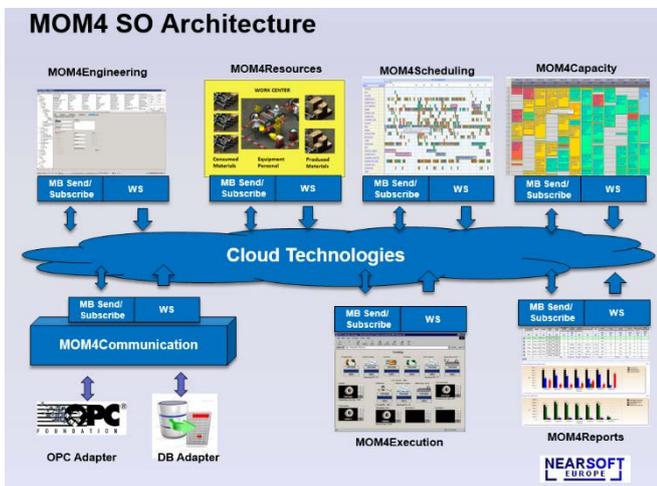


Figure 6. MOM4 SOA

The technology and architecture of the MOM4® products was designed around objects and services as defined per IEC 62264 standards and adapted to the environment of configurable Enterprise Content Management System with web based Portal and communication adapters to the shop floor automation.

MOM4® is an open Manufacturing Operation Management solution that incorporate apps for Advance Planning and Scheduling (MOM4Scheduling), Finite Capacity Scheduling (MOM4Capacity), Manufacturing Execution Systems (MOM4Execution), Data Warehousing and Analyses (MOM4Reports) and real-time performance management (MOM4Production), quality (MOM4Quality), maintenance (MOM4Maintenance) and inventory (MOM4Inventory) processes. MOM4® combines all these powerful

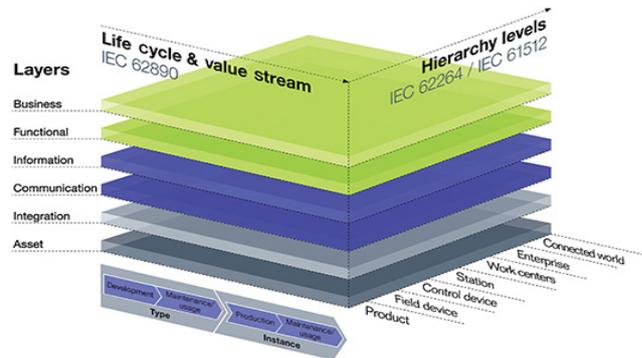


Figure 5. Reference architecture model for Industry 4.0 (RAMI4.0)[4,5]

configurable software products through a full collaboration based on functional integration and web service interfaces based on Business To Manufacturing Markup Language (B2MML), an XML/XSD implementation from the ISO/IEC 62264 standard family. They provide a flexible approach to collecting, organizing and distributing of production, maintenance and quality information throughout a manufacturing plant via and web based eCMS user experience.

The Manufacturing Model as defined per IEC 62264 is described in details inside the dedicated app called MOM4Resources. It extends the functionality of traditional Product Definition Management (PDM) and Product Lifecycle Management (PLM) systems with respect to Manufacturing Operation’s needs. MOM4Resources hold information for Materials, Equipment, People, Segments and Product Production Rules. The app could exchange B2MML data with other systems such as ERP, CAD/CAM, etc.

The MOM4® platform implementation is made to allow any combination of hybrid cloud strategy. The hardware components (Fig. 7) can be configured in different ways depending on size of the system and the specific needs.

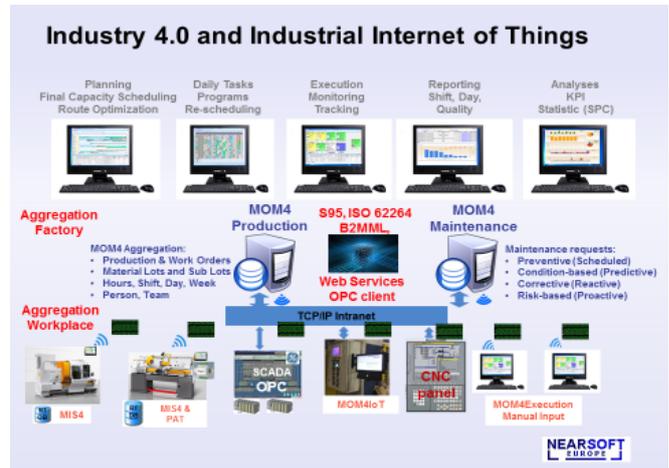


Figure 7. MOM4 and IIoT

The MOM4® enables an up-to-date content through configuration based on ever-changing customer’s requirements using standard products that provides horizontal and vertical integration trough web services, to each other or to the external systems in order to cover the whole process of manufacturing execution. The horizontal integration is implemented as web services based on B2MML standard, and the vertical one supports in addition OPC UA interfaces. The different apps are operated using configurable displays for presenting the information in the dedicated process area. That means that the user could get a complete overview of the plant and of its control system functions,

using a state-of-the-art and uniform Human-System Interface throughout web based eCMS from any device (incl. mobile) with browsers such as Internet Explorer, Google Chrome, Firefox, etc.

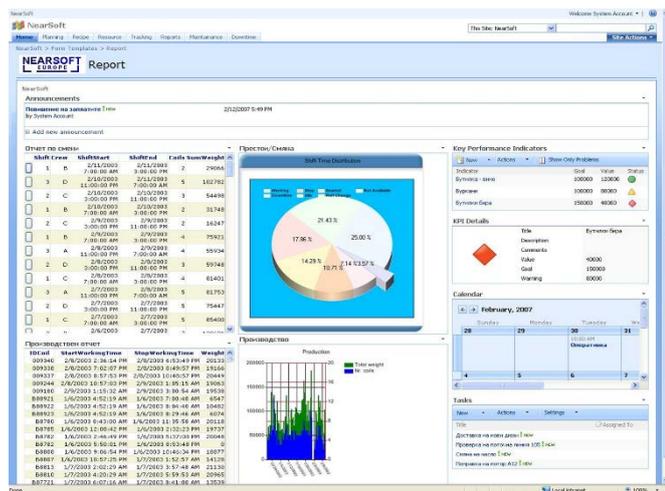


Figure 8. MOM4 interoperability with MS SharePoint

- Average value (AVG), Counters (CTR), Cumulative value (CUM), Running Hours value (RHR), Limit Check (LMC), etc.
- Provides powerful SPC instruments (Standard Deviation, Normal Distribution, Pareto Charts, Histograms, etc.) for analysing production information and ISO 22400 KPI calculation; (Fig. 9)



Figure 9. MOM4 SPC Instruments

6. Conclusions

Industry 4.0 transforms the entire business and changes the rules of the game for manufacturing. Connecting real machines with information technologies and the Internet increases productivity. The immense scope of change it brings, and the level of investment required means that it belongs on the CEO's agenda. It encompasses not only digitising both horizontal and vertical value chains, but also revolutionising corporate product and service offerings, with the final goal being to better satisfy customer requirements.

The paper try to propose an approach for the gradual migration to Industry 4.0, starting with implementation of existing apps in the MOM layer, and in this way minimizing the risk of adopting new strategies. The required technologies (including mobility, MES, Cloud, Industrial Internet, and Connectivity) are available today and we can leverage the potential by being smart, addressing specific use cases towards an evolving Industry 4.0 IT architecture.

NearSoft MOM4[®] solution is prepared and ready solution that comprises Industry 4.0 enablers in the following manner:

- Uses service oriented web based technology and it is ready for cloud distribution on a hybrid cloud;
- Achieve interoperability through user friendly configuration of the web service interfaces for communication with external systems, thus building an entire Industry 4.0 ecosystem (B2MML, OPC UA, Barcode printers, RFID, etc.).
- MOM4[®] is entirely built based on the standard IEC 62264 (ANSI/ISA S95) that provides unified approach (objects and models) for integration with other information systems;
- Provides data collection from different sources and realizes following aggregation functions Min (MIN), Max (MAX),

An innovative solution for integrated manufacturing operation management has been presented. MOM4[®] fulfils customized customer requirements with state-of-the-art industry software that links all stages of the value chain through standardized interfaces. It consists of interoperable products that could be deployed on any hybrid cloud environment. MOM4[®] is developed for agile smart manufacturing supported by the right information to the right person or system at the right moment with fit-for-purpose instructions. Technology-wise it is a melting pot that combines Big Data technologies; new generations of human-machine interfaces and reliable layers of ubiquitous connectivity, to manage the flood of information from smart machines, connected workers and the products themselves. MOM4[®] solutions, utilizing Product Control Flow concepts, connect the physical machines, products and people with the IT-systems and applications to form a manufacturing execution layer (MOM/MES). With the MOM4[®] now able to represent actual demand and capacity, production schedules and plant configurations can be optimized and replenishment of materials triggered in real time for the next order arriving.

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