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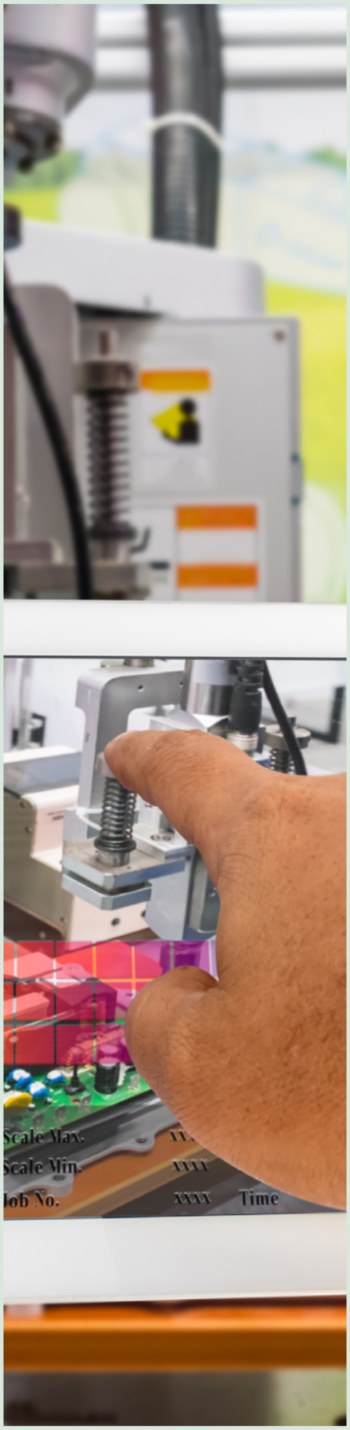

MANUFACTURING EXECUTION SYSTEMS: DIGITAL FOUNDATION FOR SMART MANUFACTURING

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Executive Summary

Globally manufacturing industries embark on digital transformation to improve productivity, increase efficiency, reduce the cost of operations and increase market share with product and process innovation. This digital transformation for smart manufacturing requires adopting many information and operational technologies that align with the current landscape of manufacturing technologies. This requires foundational technologies to scale and evolve into diverse functions of Smart Manufacturing. Many manufacturing organizations have Manufacturing Execution System (MES) for production management and collaboration. MES provides the power of real-time visibility of operations and drives production execution. Smart manufacturing requires end-to-end control across manufacturing and the value network with both horizontal and vertical integration. The benefits of smart enterprises adopting Industry 4.0 concepts is enticing for all types of enterprise – process, discrete or continuous manufacturing, but the path is not clear.

This paper addresses digital transformation with MES as the core element combined with other relevant technologies. Further, the paper analyzes the different requirements of smart manufacturing. It provides insights into the alignment of MES technology for this digital journey. MES being a data hub for all production events provides the most suitable platform to help realize many business functions in production, quality, inventory and maintenance operations. In this way, MES accelerates solution implementation for smart manufacturing. The workflow capabilities, real-time production data and contextual information of MES provide a convenient platform for adopting different technologies like Industrial Internet of Things (IIoT), analytics, robotics, and immersive technologies to equip manufacturing operators and decision makers better to make operational, tactical and strategic decisions. It also provides a pragmatic roadmap to implement smart manufacturing for specific use cases.

Smart Manufacturing Drivers

The global smart manufacturing market is predicted to grow from USD 175 billion (2020) to USD 303 billion by 2026, with a compound annual growth rate (CAGR) of 6.4% between 2019 and 2026[1].

The manufacturing industry is undergoing a sea change –

- The automotive sector is witnessing a revolution with electric and hybrid vehicles
- The pharma sector is forced to shed long cycle product launches to meet the pandemic demands and also customized drugs requirements for patients
- The CPG sector is dealing with increased regulatory compliance requirements
- The aerospace industry is looking at significant productivity improvement owing to the tough business environment

Smart manufacturing will play a significant role in helping firms in these sectors wade through the changing dynamics. Smart manufacturing solutions have been designed to manage the key capabilities like enabling the digital thread from configure to order to dispatch, production transparency, scheduling, traceability, analytics, energy and waste management, and quality management powered by connectivity options on a secure backbone.

Manufacturing Execution Systems

MES continues to be the mainstay for production and operations management across a multitude of industries. The present MES market is USD 11.56 billion and is forecast to grow at a healthy CAGR of 15.4% to USD 27.3 billion in 2026. MES has been a huge success in many of the process industries, hi-tech and general manufacturing sectors. With a huge install base across industries and a growing reliability and maturity of its capabilities, MES is turning into an apt foundation for building smart manufacturing plants, optimizing operations and expanding markets. In addition, it further enables digital operations to minimize costs and create new avenues for growth.

With the advent of other manufacturing IT technologies like IIOT and Industry 4.0, immersive technologies like AR/VR, there are queries about how these technologies complement or compete with existing technologies like MES owing to insufficient clarity on creating a digital transformation roadmap. Therefore, organizations are looking for the best ways to combine and adapt solutions, including MES and these newer technologies, to transform themselves into smart digital manufacturing. This transformation provides the much-desired business outcome of hyper flexibility in manufacturing, optimized processes and agile organizations. It also makes it easier to set up operations, expand revenue and churn out new business models.

This paper charts out a roadmap for realizing the transformational goal of smart manufacturing, with MES being the firm foundation. It provides insights on exploiting the MES layer to support the other pillars of manufacturing technologies to achieve this challenging goal.

Smart Manufacturing and the role of MES

Capabilities of smart manufacturing

Smart manufacturing requires flexible production capabilities, including varying configurations based on customer need, self-adaptation and intelligent operations. It seeks to speed up design, time to market, reduce the cost of goods produced, improve end-to-end traceability, revolutionize service effectiveness and support newer business models. End-to-end visibility, efficiency coupled with effective decision-making during manufacturing and the ability to input the manufacturing knowledge back to design and R &D make these outcomes possible.

It integrates manufacturing assets, control systems, information and computational systems, simulation and modeling with manufacturing systems and processes. Smart manufacturing can also integrate with modern IoT platforms to consume data from analytics engines and time series DB for enhancing production execution.

MES - The foundation for smart manufacturing

Flexible production requires dynamic changes in production scheduling and routing as per demand. Production setups need to change for product changeovers, followed by configuration and testing. Scheduling needs to match with customer demand for varying product configurations, turnaround time, available production capacities, inventory, raw material, resources and may require seamless coordination between multiple production plants to meet the demand. Central to addressing this need is the MES, which receives production order and dispatch requirements, facilitates execution of production tasks and captures data from shopfloor systems for reporting and analysis.

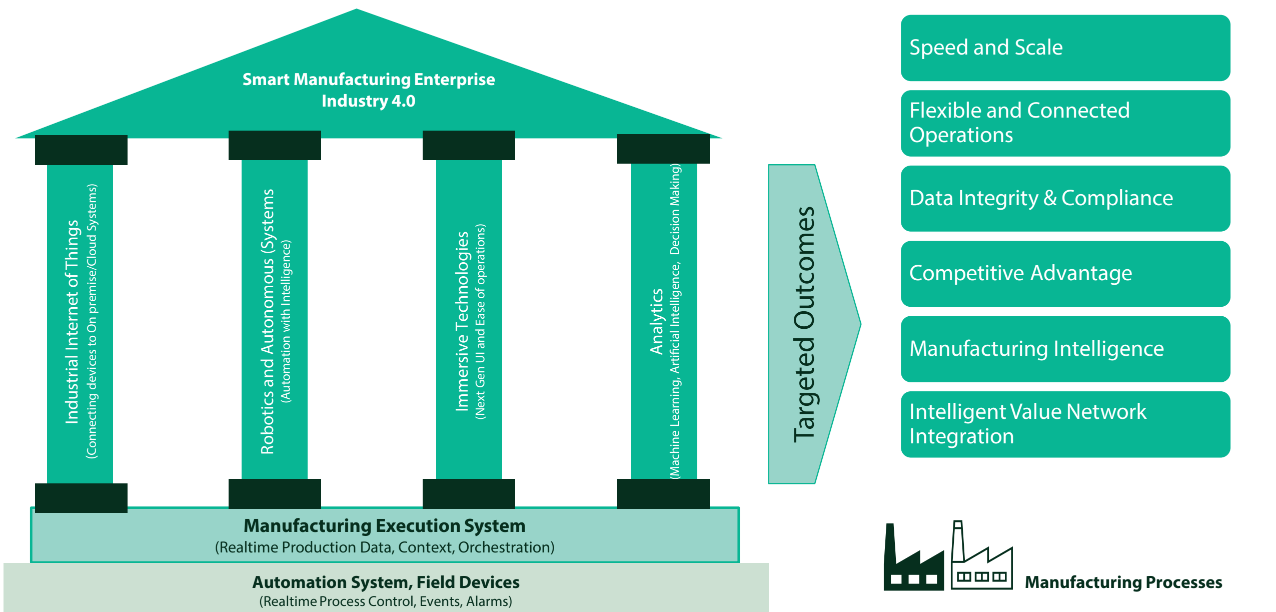

Figure 1. MES as a foundation for Accelerating Smart Manufacturing

MES provides the right foundation for digitization with Industry 4.0 because of its need for both horizontal and vertical integration across the automation hierarchy and becoming the system of records for all production data (Fig 1).MES integrates data domains across the value chain for enabling intelligent operations – materials supply, equipment management, production quality, distribution network and end customer. Data for a common information model suiting the manufacturing and other business systems is possible with the real-time production repository in MES. Rapid setup of machines and data capture in changed scenarios is another key capability to be addressed by MES.

Many strategic and tactical decisions for manufacturing require sound data. MES is the orchestration hub for all manufacturing processes and workflows as it extends across the plant floor to top floor seamlessly to achieve agile production management. Further, it has eased interactions with enterprise systems, production visualization, order tracking and provides a system of record for production. With its capability to provide real-time information on plant performance and ability to enable quantifiable production KPIs, inter and intra plant production comparison becomes possible. Further, with the ability to trace back to individual manufacturing activities, be it machine, personnel, material or manufacturing process backed with IT/OT convergence, near real-time root cause analysis becomes possible

These have led to many manufacturing organizations using MES as a cornerstone to build the information pipeline and enable strategic decisions across the manufacturing value network leading to competitive advantage and improved margins. In fact, vendors have developed specific MES products suited for different types of manufacturing – discrete, batch or continuous.

Smart Manufacturing: technical considerations, MES alignment and maturity requirements

The implementation of smart manufacturing requires data from diverse sources across the enterprise. It needs close cooperation between different business domains such as supply chain, planning, finance, engineering, manufacturing and customer service and is driven by the need for real-time data needs with high integrity. Naturally, this involves a confluence of technologies ranging from cyber physical systems, intelligent sensors and machines, connected systems utilizing IoT, production automation, intelligent networking, cloud computing, open standards for communication, AI/ML, robotics, digital twin and analytics.

This section describes the important technical considerations for smart manufacturing and its alignment with a mature MES platform:

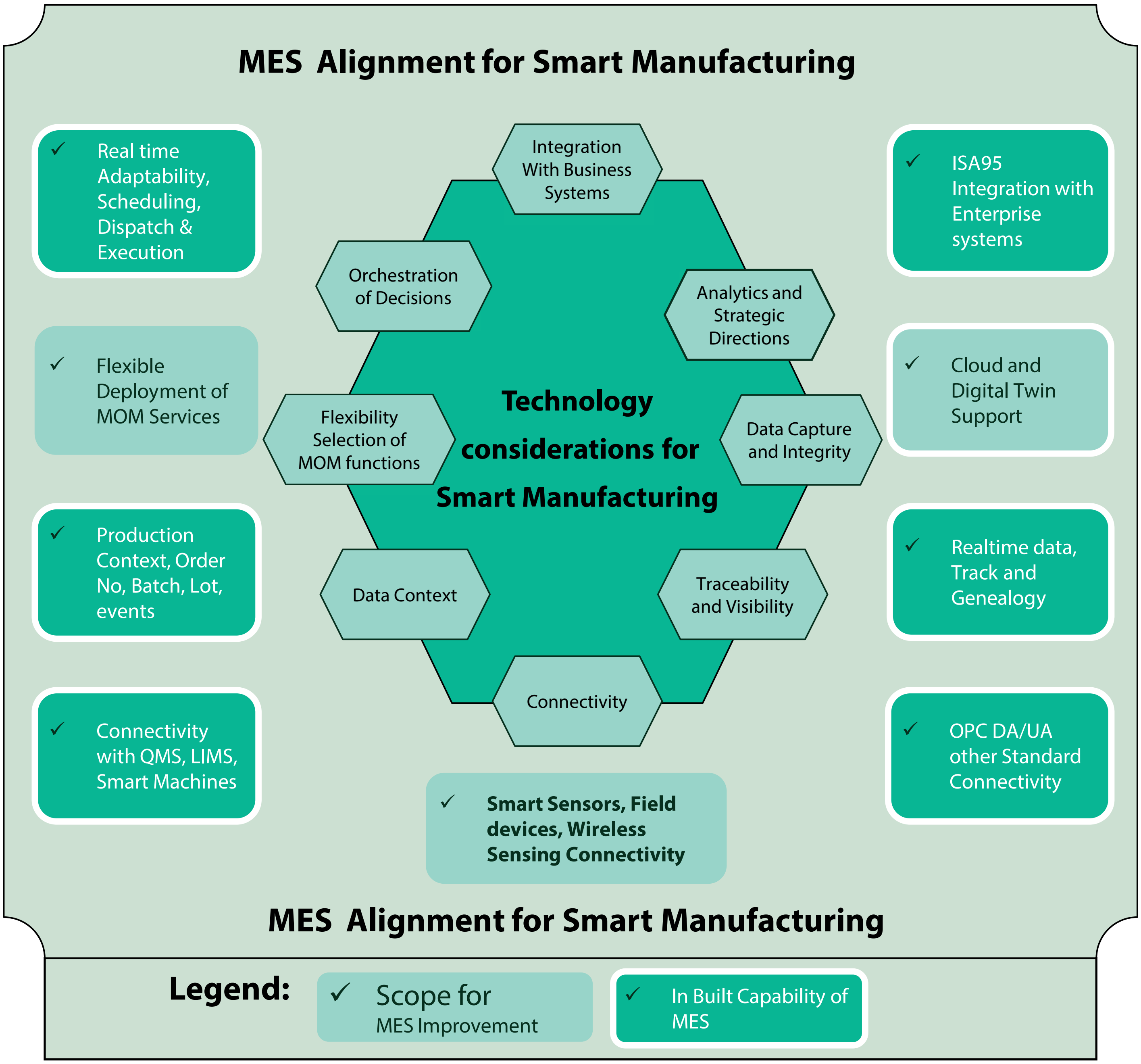

Figure 2: MES Alignment and Maturity for Smart Manufacturing

Connectivity and Integration:

Smart manufacturing requires horizontal integration between machines, machine systems, applications, as well as vertical integration connecting the various plant floor systems to business systems. Therefore, it is not only important to connect the value chain from sourcing to manufacturing to end customers but also the value network of vendors, partners, other internal and external stakeholders to truly realize a smart manufacturing enterprise.

Data capture from diverse machines and sensors are required for manufacturing. This includes data captured based on automatic triggers or event driven. Further, there is a need for support of diverse protocols for data capture from these systems and could be wired or wireless. MES supports data capture based on the universal OPC DA/OPC UA standards. MES connects with many DCS, PLC, CNC systems, historians, LIMS systems and enterprise systems like ERP systems.

As manufacturing organizations aim for more agility in their production process, new product introduction requires integrating design systems to MES for faster and smooth integration of product data models into the machines. The manufacturing processes laid out need further digitalization as the operators would have to ultimately use them with ease on the plant floor and would require training. Visual aids and simulation tools help to dynamically reschedule production schedules and quickly onboard operators thereby increasing operational effectiveness in both manufacturing and maintenance. This need is driving the integration of MES to simulation and training management systems. This integration pays dividends as process and product data from design systems help to fine tune production processes, machines and tools, reducing the iterations of design, thereby achieving reduced time to market. Integrating MES with PLM systems has become a key requirement to form the complete digital thread.

As IIoT becomes more mature and reliable, smart manufacturing relies on feedback from analytics and AI engines to improve decision making. First, however, MES needs to provide APIs to help connect with multiple IIoT platforms.

Data integrity: The most vital aspect of data for smart manufacturing is its integrity and reliability for further use downstream for aggregation, analysis and decision making. MES is the central hub for all production data from the whole plant area. It has operations data on inventory, quality and maintenance. MES is the origin where the customer data, work order and production data are tied together and is the key data source for traceability.

Data context: Central to building smart applications is data with the right context. A production event like stoppage, defect or a process value deviation can be best understood through MES as it has the data model to associate events based on process types, workstations, work centers, area, equipment and operators. This can be overlayed with the data viewed from the lens of operations to understand the holistic scenario, thus making it invaluable. A similar level of information cannot be obtained from just plant automation systems or an IIoT platform as they lack the operations layer data.

Traceability and visibility: Smart manufacturing is all about connecting different dimensions of data to create value networks that proactively enable intelligent decisions in almost real-time. It also strives to drive autonomous decision making which requires traceability of manufacturing, material, and visibility into operations ordering, demand and supply. With its central data repository, real-time plant information and the ability to provide production data context, MES has the unique advantage to make available the required data to realize the production and material tracking with genealogy. This single platform with its unique data model embodies tremendous volume as well as the depth of information that accelerates the implementation of smart manufacturing solutions.

With multiple new technologies like NFC, LTE, RFID, smart manufacturing has started addressing many complex legacy issues related to traceability. Smart manufacturing can now expand traceability to raw materials, AGVs, test jigs, tools, finished goods and pallets. MES must be enhanced to complement and expand the existing genealogy tracking to other areas as required in smart manufacturing.

Analytics and strategic decision making

Real-time analytics drives decision-making in smart manufacturing. The analytics spans a wide arena, including manufacturing, supply chain, planning, customer preferences and compliance. It plays a significant role in many use cases - be it aligning of manufacturing scheduling based on dynamic demand, flexibility in terms of production changeovers, reducing time to market for new products, take decisions on process improvement and improving efficiencies, root cause analysis of quality defects, handling of compliance issues or tweaking product characteristics on customer survey/ feedback. Analytics requires data like details of manufacturing batch, information on processing, equipment, quality data, capacity and capability of manufacturing, conditions, and status of work in progress which are the core details derived from the MES data model. Coupled with this data from MES and using the standard libraries of AI/ML in an IIoT analytics platform can provide the wherewithal to unleash the power of business analytics for smart decision making.

Orchestration of decisions: The final outcome of these decisions is a well choregraphed orchestration of the individual decisions at operational, tactical and strategic levels. As smart manufacturing demands more situational awareness-based decision making, there is a significant dependency on the data orchestration layer to provide the right stakeholders with the right data at the right time. MES acts as the orchestration platform for manufacturing with its in-built capability for production execution, performance monitoring and transparency. The visibility of production data across the value chain to multiple stakeholders provides trust and improves collaboration. MES supports information integration and orchestration of production orders, plant performance, bill of materials and routing. It also provides data for tracking, costing and optimization. Even when there is intelligence in machine systems, it needs to interact with MES to get production orders, material allocation and execution of orders across work centers.

MES needs to enhance its ability to orchestrate information coming from multiple IIoT platforms and simulation systems. IIoT provides the ability to monitor plant operations and has limited control possibilities as it does not have the operations information. IIoT can increase the type and volume of data from manufacturing. IIoT brings in a flatter architecture bypassing the traditional multilayered automation architecture. But, to realize more beneficial analytical use cases and control of production, it would need additional contextual data like that in MES. On the other hand, MES would do well to have additional data from the IIoT devices for maintenance, storage, predictive analysis or operational events where the traditional PLCs/DCS cannot source them.

Flexibility: The MES solution needs to be flexible, and the existing monolithic structures should evolve into microservice based architectures to cater to an enterprise's varied needs. MES platforms implement modular functions based on the MES framework. Microservice based design provides additional capability and flexibility in deployment. MES architectures on cloud are also evolving and with robust security and scalability. The upcoming 5G communication capabilities will only accelerate this trend.

The adoption of these technologies needs alignment with the larger business vision and strategic planning. The existing technical ecosystem needs to be evaluated before putting up new platforms for adoption. A technical roadmap aligned to the business needs is a basic requirement in charting out the direction and pace for the smart manufacturing solution. The horizontal and vertical integration within a plant and the enterprise systems create a value network and form the core engine. Process and production data are key for this value network creation. Process data historian and the MES acting as the system of record for this data provide a full context for both process control and goods produced that too in real-time and assured data integrity.

Further, both these are proven technologies which can be scaled to fit any manufacturing organization. Additionally, there are cloud solutions of MES, which are used for functions like an operational dashboard, quality analytics production scheduling and planning. They provide additional capabilities to integrate across the supply chain and provide timely information for manufacturing decisions.

Many automation solution vendors of distributed control systems (DCS), programmable logic controllers (PLCs) like Rockwell, Siemens, Emerson etc., have diversified their product portfolio to include manufacturing IT solutions like MES and manufacturing intelligence. Similarly, ERP vendors like SAP, Oracle, Microsoft have extended their solutions to include manufacturing and operations, IIOT and cloud computing.

Planning and Scheduling:

Smart manufacturing thrives on its dynamic ability to plan and schedule production execution tasks. MES has traditionally been able to use its finite and infinite capacity planning techniques to schedule production execution to a highly granular level utilizing all the resources in the shop floor, including people, machines, inventory and tools. As the market drives more competition and productivity improvement, smart manufacturing solutions are challenged to be more dynamic and near real-time in their planning and scheduling. Planning and scheduling, usually a component of production execution in MES, is now required to monitor the real-time status of the resources, including people, machines, inventory and tools. It is then expected to modify the schedule and notify the corresponding impact to all associated functions inside the factory and other dependent factories.

Energy and waste management

The production efficiency in the modern smart manufacturing setup expands beyond the regular turnaround time and OEE. Organizations now need to include energy consumption and waste generated as core productivity and sustainability indexes. Building management systems (BMS), weighing scales are being enhanced to manage and orchestrate energy and waste information as MES can interface with energy meters.

Condition monitoring

As machinery in the factories age, smart manufacturing demands organizations to start monitoring the health of these assets in real-time. This is important for planning and scheduling, which is directly impacted by asset availability. MES, traditionally managing production downtime analysis is being expanded to manage the presentation of asset health data also in a smart manufacturing setup. Further, the predictive health information that is determined using machine learning modules in the IIoT Platform is also routed via MES to the corresponding stakeholders to plan the production and maintenance activities.

Security

As smart manufacturing becomes more connected and interactive, the system also becomes more susceptible to cyberattacks. MES and all the other software integrated to form the smart manufacturing setup should comply with ISA/IEC-62443 (formerly ISA-99) standard to ensure risk-free operations. In addition, all systems and network components forming the constituents of smart manufacturing need to be secured.

Roadmap for smart manufacturing

The roadmap can be realized by enabling the technical architecture to facilitate use cases on identified themes for smart manufacturing. The themes are based on tackling decision making at the operational, tactical and strategic level like a connected plant, connected team, smart quality and smart analytics (Fig 3). Use cases identified across all these themes progressively shape the conceptual vision and evolve the technical architecture.

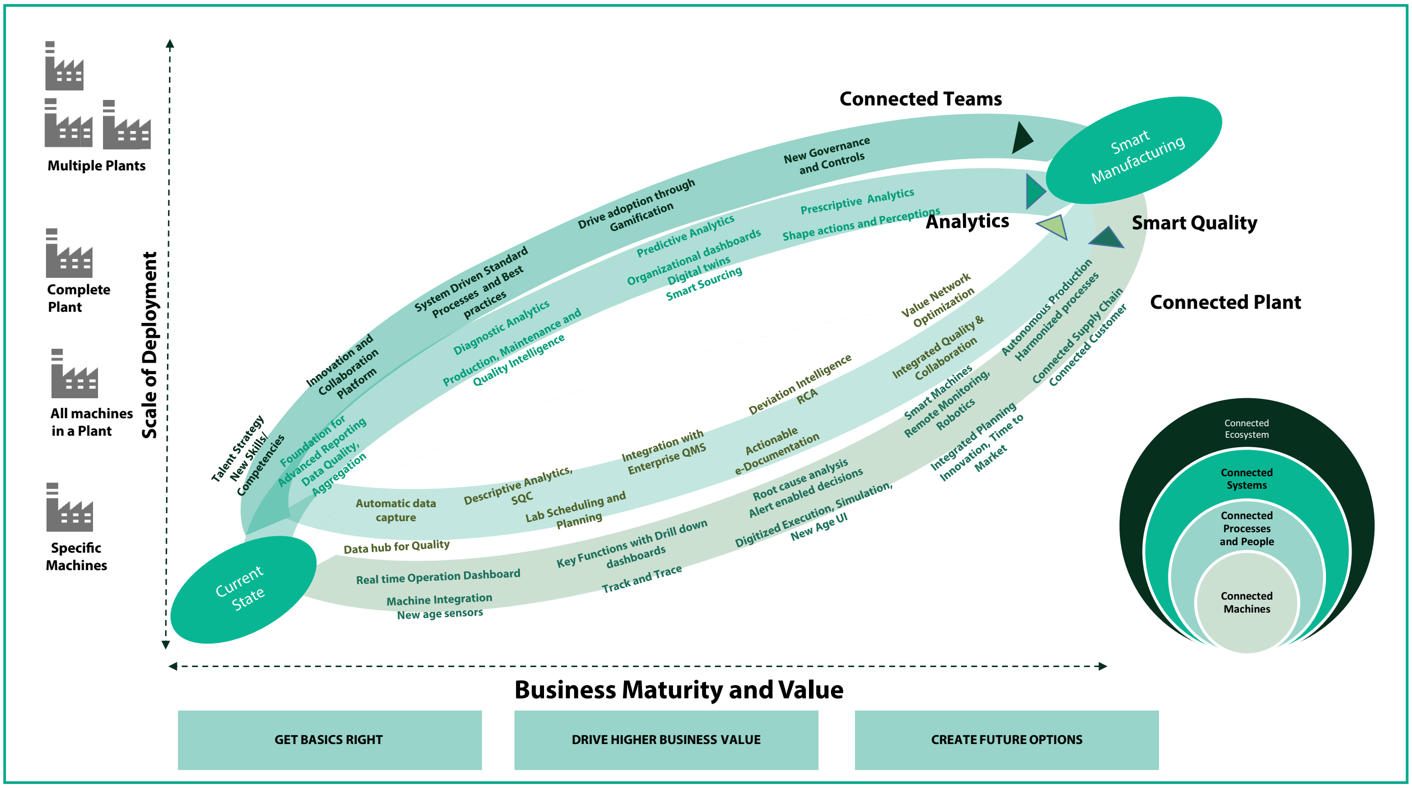

Figure 3 Roadmap for Smart Manufacturing and sample use cases

Smart manufacturing with Industry 4.0 is a strategic priority, but it is challenging to drive these values at scale. A strong foundation of data platforms can help these solutions scale[2].

The first phase sets up a solid technical foundation. Some recommendations on this front include –

- Opt for standards based open connectivity to support scaling of different types of devices and machines
- Have a data aggregation and system of records separately for process data and production data
- Adopt cyber physical production systems and smart sensors.
- Ensure reliable data foundation layer with high data integrity.

In the second phase, the focus is to drive higher business value by adopting smarter machines and integrating systems, processes and people. The organization must also adopt a newer cultural model and new technical skills.

MES forms the foundation for connecting different systems. It links both the physical production system on the shopfloor and the business systems at the top and can integrate horizontally and vertically (Fig 4).

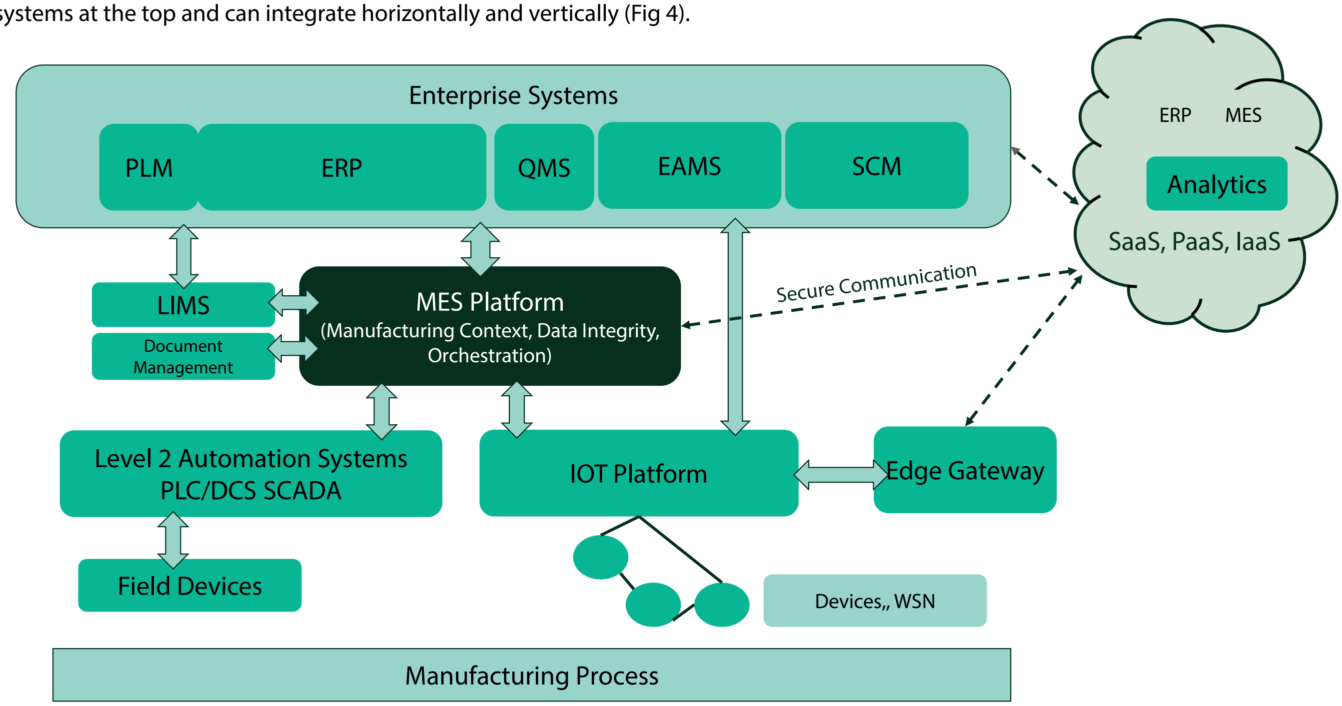

Figure 4. Conceptual view of technical landscape with Core MES for smart manufacturing

Interfacing smart devices and IIoT to MES provides additional dimensional data for analysis and decision making. The MES integration with shop floor control systems provides access to process data, events and the process alarm details for decision making at different levels. Production can be planned, sequenced, prioritized and tracked with this information. Further, MES-ERP integration drives production scheduling, order tracking and adjusting production to demand. Desired automation for quality monitoring and production capacity planning then becomes feasible. Additionally, it provides real-time visibility of plant performance, decision points for resource allocation and cost optimization. This integration is well defined by open standards like ISA 95 and supported by many MES products in the market.

Application integration of MES-PLM enables quick design reviews, checks for feasibility for manufacturing and fine tuning the bill of process and other tools used. It accelerates decision making on design projects, time to market and enables the realization of digital twins. Ensuring a pipeline of real-time data across the system into a common analytics platform drives smart analytics leading to smarter decision making.

Adopting new-age UI, AR/VR technology increases the ease of operations and increases the acceptability of these technologies. The third and final phase involves integrating the systems across the value network.

End-to-end digital thread

Smart manufacturing focuses on an end-to-end digitally managed thread with a continuous feedback loop from customer to factory, factory to customer and usage information back to R & D. Each of the systems involved in the loop should be able to talk to each other and complement the functionality to enable optimized output and dynamically traceable information facilitating quicker decision making and reduced overall complexity as shown in Fig 5. MES forms the centerpiece to this overall digital thread enabling seamless execution management of production requirements.

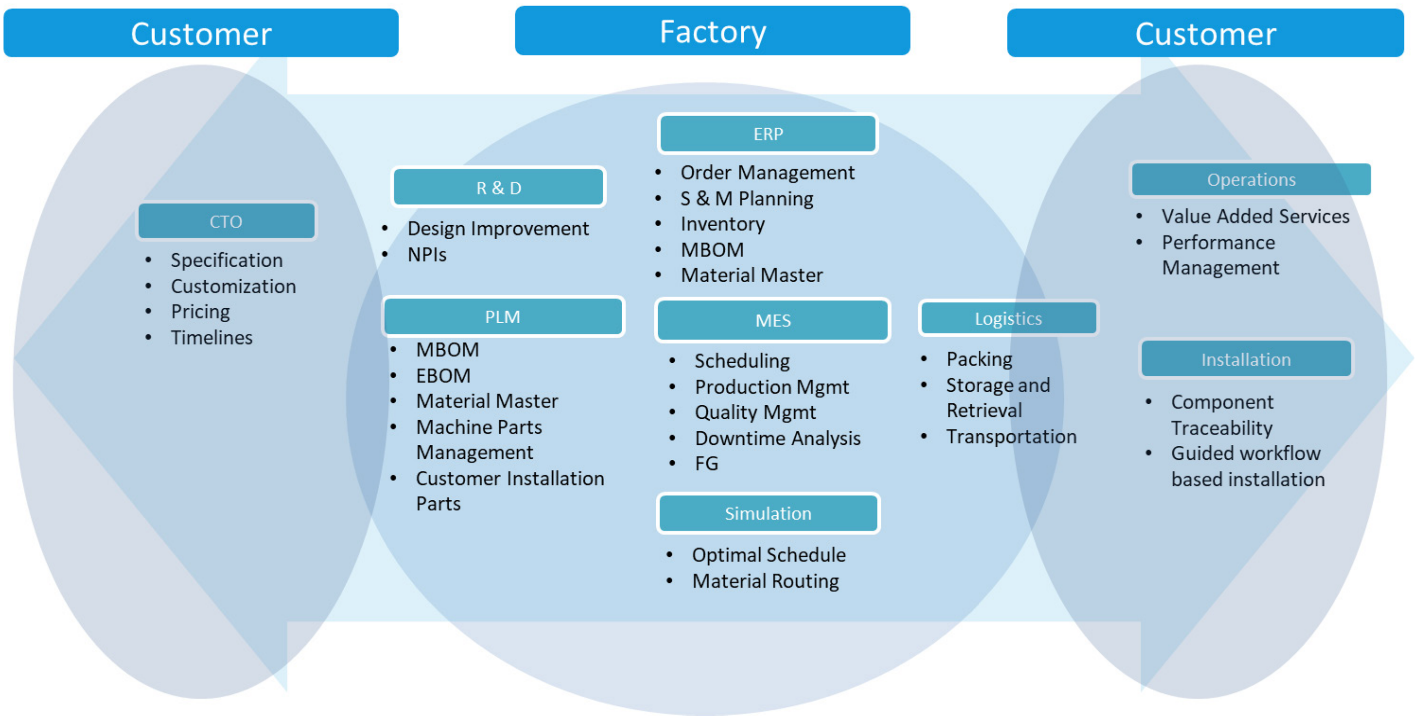

Figure 5. End-to-End digital thread for smart manufacturing

Driving smart manufacturing with MES

In recent years, the concept of smart manufacturing has gained ground as it helps businesses become more competitive and forge market leadership. As a result, it is rapidly expanding in discrete, process and continuous manufacturing sectors.

Organizations and technology bodies have come up with their methodologies, frameworks and guidance to help customers transition to smart manufacturing. Acatech Industry 4.0 maturity model is one such framework that helps customers determine their current state of maturity and evolve to smart manufacturing by deciding on the right capabilities to focus on (Fig 6).

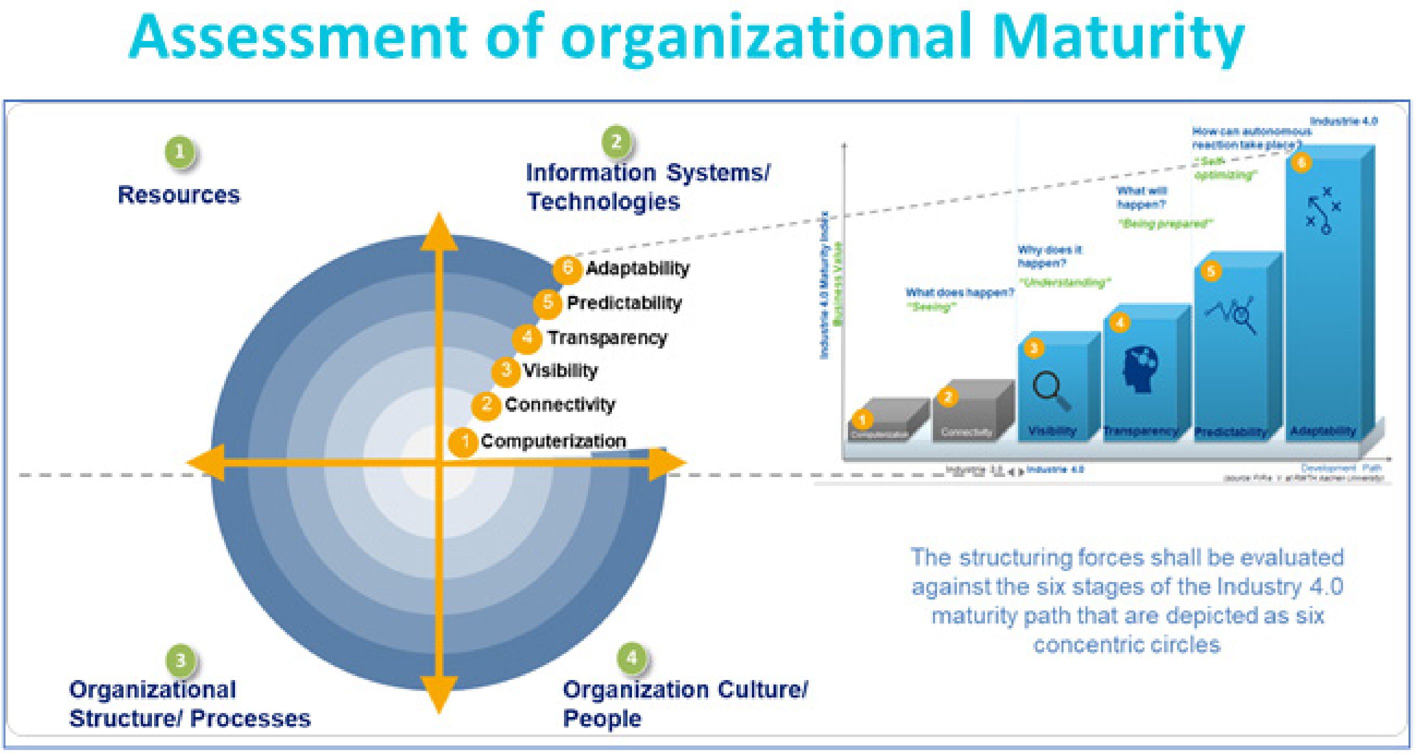

Figure 6 Acatech Industry 4.0 assessment framework

Smart manufacturing has also influenced adjacent industry players compelling many big players of automation and ERP to enter the fray with their offerings.

Automation solution OEMs of DCS, PLCs like Rockwell, Siemens and Emerson have diversified their product portfolio to include manufacturing IT solutions like MES, IoT and manufacturing intelligence. Similarly, ERP vendors like SAP and Oracle have extended their solution to include manufacturing and operations as well as IIoT.

Large enterprises and cloud solution suppliers like Microsoft and Amazon have come up with their accelerators too. In addition, there are a plethora of new IIoT and analytics platforms offering SaaS solutions. There are on-premises MES solutions from many reputed MES vendors and MES on cloud or SaaS based offerings from many emerging players like Flex, Tulip and Critical Manufacturing[3].

Customers have plenty of options to choose from, but they need to build on a vision with careful analysis and planning before embarking on the design and implementation of solutions.

Conclusion

The transformation of manufacturing enterprises to smart manufacturing is on the ascent, with many sectors taking steps to adopt them. This journey is rife with technical challenges as manufacturing technologies are varied, making radical changes difficult and not always practical. Nevertheless, smart manufacturing is here to stay and promises attractive business outcomes. Enterprises have different technical options to choose from and adopt. However, there needs to be a holistic evaluation of the enterprise's technical, process and cultural landscape before embarking on this journey. Utilizing the existing technical landscape with MES as the foundational component while co-opting newer technologies like IIoT, Industry 4.0 and cloud technologies is a rational choice. The roadmap towards autonomous systems needs to be built on firm foundational technologies which are proven, scalable yet flexible. MES technology offers a stable choice to build and shape future digital enterprises. The calibrated approach of quick wins and building on a technological roadmap that aligns with the enterprise's business vision generates rich dividends.

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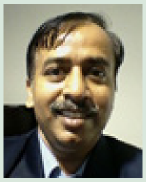

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