Closed-loop manufacturing

Using manufacturing operations management to power smart manufacturing

This white paper explains the challenges manufacturers will face on their digital transformation journey, and what they can do to take advantage of the promise of this new industrial era. We will discuss how to create a technology infrastructure capable of harnessing the power of massive data and converting that data into greater efficiency and quality.

Growing innovation requires a new manufacturing paradigm

With product innovation comes increasing manufacturing complexity – not only for products, but for the processes required to manufacture them, and the types and volume of data the products and processes produce. It is daunting for humans to attempt to work efficiently with manual processes amidst this complexity.

At the same time, innovation in the manufacturing space offers significant opportunity for advancing efficiency, quality and intelligence.

Overcoming the challenges of innovation while leveraging the advantages new technology offers requires a new manufacturing paradigm.

This new manufacturing paradigm will require new sources of data to operate in concert, to be connected, integrated and understood in context across the entire value chain – a value chain of products and production processes. We call this state closed-loop manufacturing (CLM).
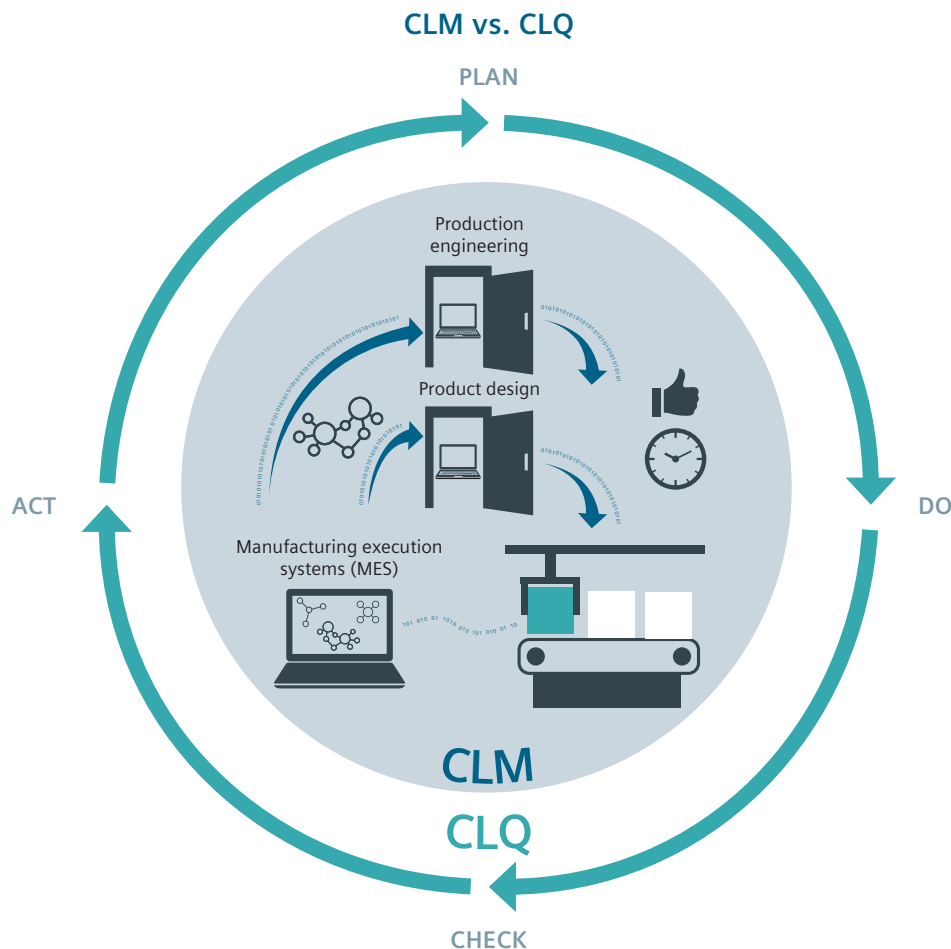
Defining closed-loop manufacturing

The cornerstone of the digitalization journey is closed-loop manufacturing, so let's define the concept of CLM.

CLM enables firms to synchronize and optimize production across product design, production planning, manufacturing execution, automation and intelligence from consumer use in the field. Creating a collaborative, connected information loop, CLM continuously improves the cost, time and quality of the manufacturing process to accelerate the delivery of products at the optimal level of quality and cost. Using CLM tightens the alignment of the as-planned product with the as-built and as-used product in a continuous, iterative process.

Closely coupled with CLM is closed-loop quality (CLQ). While the focus of CLM is on synchronizing highly efficient production of the current product, the focus of CLQ is on improving the quality of the product across the entire product lifecycle.

CLQ is a continuous process of plan-do-check-act, evaluating the quality of the product at each stage of the product's ideation, realization and utilization, and feeding quality information back into the production and design processes. Its purpose is to ensure the quality of the current product, and feed intelligence back into design to improve the quality of the next-generation product.

This white paper focuses on how closed-loop manufacturing is essential for a manufacturing enterprise to thrive in this new era of smart manufacturing, and why it is a cornerstone of your digitalization journey. It also touches on how CLM supports CLQ. The two cannot exist in isolation.

CLM vs. CLQ

PLAN

Production engineering

Product design

Manufacturing execution systems (MES)

ACT

DO

CLM
CLQ
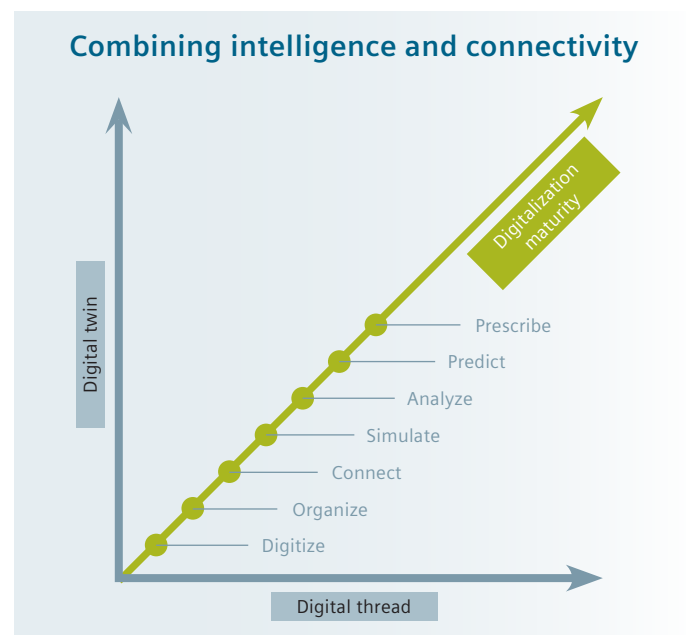
CHECK

Underpinning closed-loop manufacturing

There are two important vectors in digital transformation. These vectors are the underpinning of CLM as well as CLQ. The first is the digital thread. The digital thread is the chain of information connecting all participants with the applications and information they need to design, build and suppport innovative, smart products. The digital thread extends through the IoT connecting to devices, sensors and controllers, providing performance data for analysis.

The digital twin is an accurate virtual representation of the product, its manufacturing processes and intended use. It predicts and optimizes the product's performance in the physical world. The greater the accuracy of the digital twin, the greater the value in predicting performance.

The digital twin allows you to predict in the virtual world how something would look, act or perform in the physical world. It is fed by information from the digital thread. The strategy of bringing together the digital thread and the digital twin requires that tools and systems be able to communicate with each other. Communication means the various systems and tools need to have access to, and understand the language of the others.

The real value of digitalization and business transformation occurs as a company's digital thread and digital twin capabilities mature, transforming business processes and enabling CLM.

As systems engineering provides the digital twin of the product, and manufacturing engineering provides the digital twin of production, the big data produced is synthesized and interpreted with the appropriate analytics. We are then able to create a high-quality, agile and efficient manufacturing enterprise. That enterprise transforms from simply a more efficient operation to one that is focused on delivering innovation with speed and quality.

Combining intelligence and connectivity

Digitalization maturity

Prescribe
Predict
Analyze
Simulate
Connect
Organize
Digitize

Digital twin

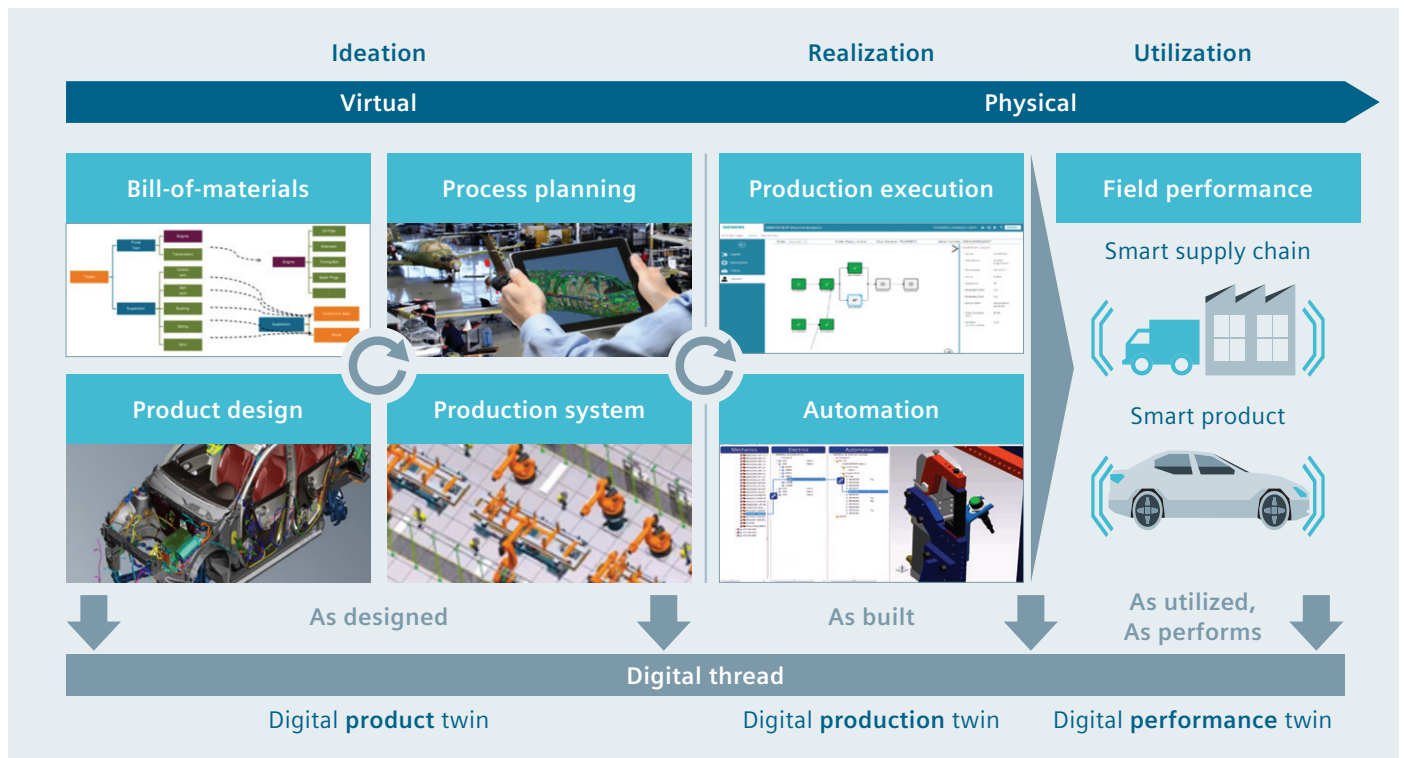Digital thread

Architecting the Digital Enterprise

So how does the digital twin and digital thread relate to the entire architecture? We look at the three phases of manufacturing: ideation, realization and utilization.

In the ideation phase, we envision and design the product, and the process by which it will be realized. Here both the product twin and the production twin are created, leveraging intelligence brought through the digital thread from across the product value chain.

The product twin strengthens product development through systems engineering and simulation. The production twin integrates product and production, allowing better manufacturing processes to be developed by anticipating the impact on efficiency, cost and quality.

The performance twin aggregates analytics across the entire lifecycle, leveraging the IoT. That intelligence is fed back through the digital thread to improve design and production.

All of the above is to make the realization phase as efficient as possible at producing high-quality products. MOM closes the loop around the virtual and physical realms. Thus, we call it the heart of closed-loop manufacturing.

Building closed-loop manufacturing

Systems required to build CLM must be architected with a digital strategy in mind.
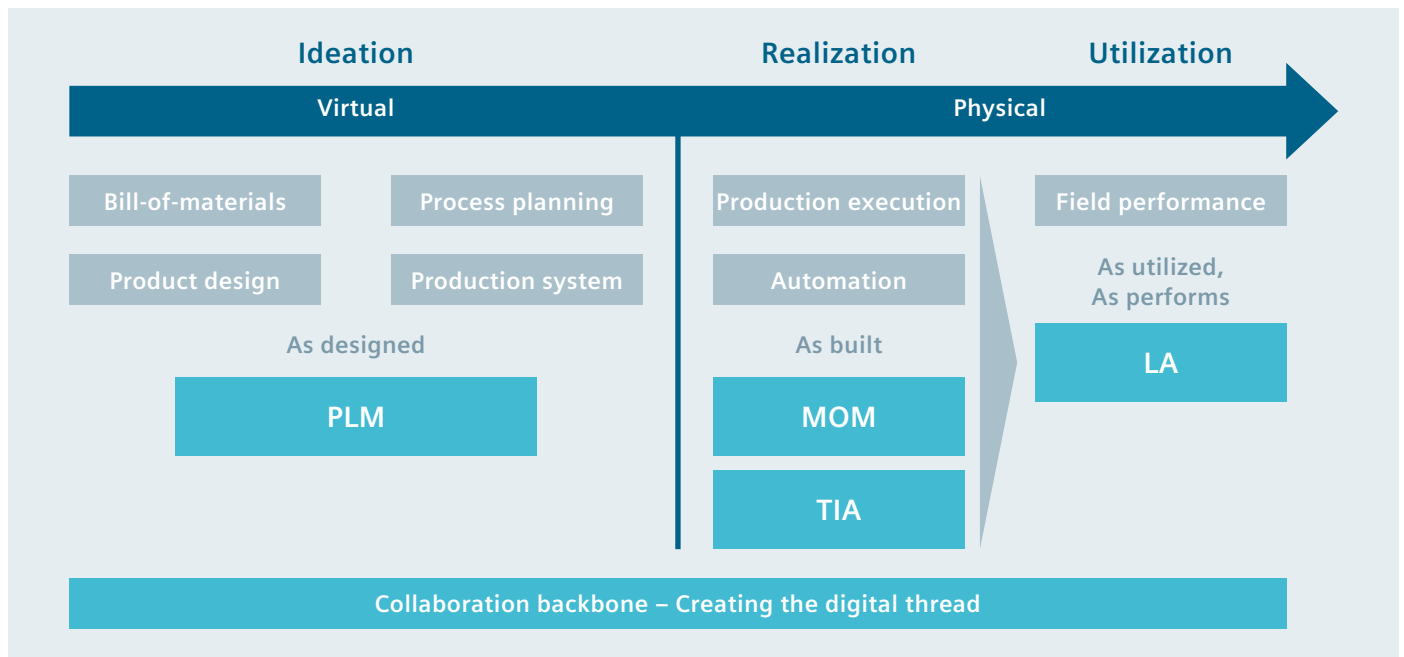
The collaboration backbone carries the digital thread to seamlessly integrate all other solutions.

Product lifecycle management (PLM) is the key to converting new ideas to marketable products faster. PLM solutions weave the necessary digital thread along all phases of development and manufacturing.

MOM is the real-time software layer that links PLM to automation, connecting the virtual world of product development with the real world of production.

Lifecycle analytics (LA) is the aggregation of intelligence across the entire product lifecycle, serving it up in contextually relevant functions to improve quality and performance.

Totally integrated automation (TIA) enables seamless horizontal interoperability between automation technologies, and vertical data integration from the field to the enterprise level.

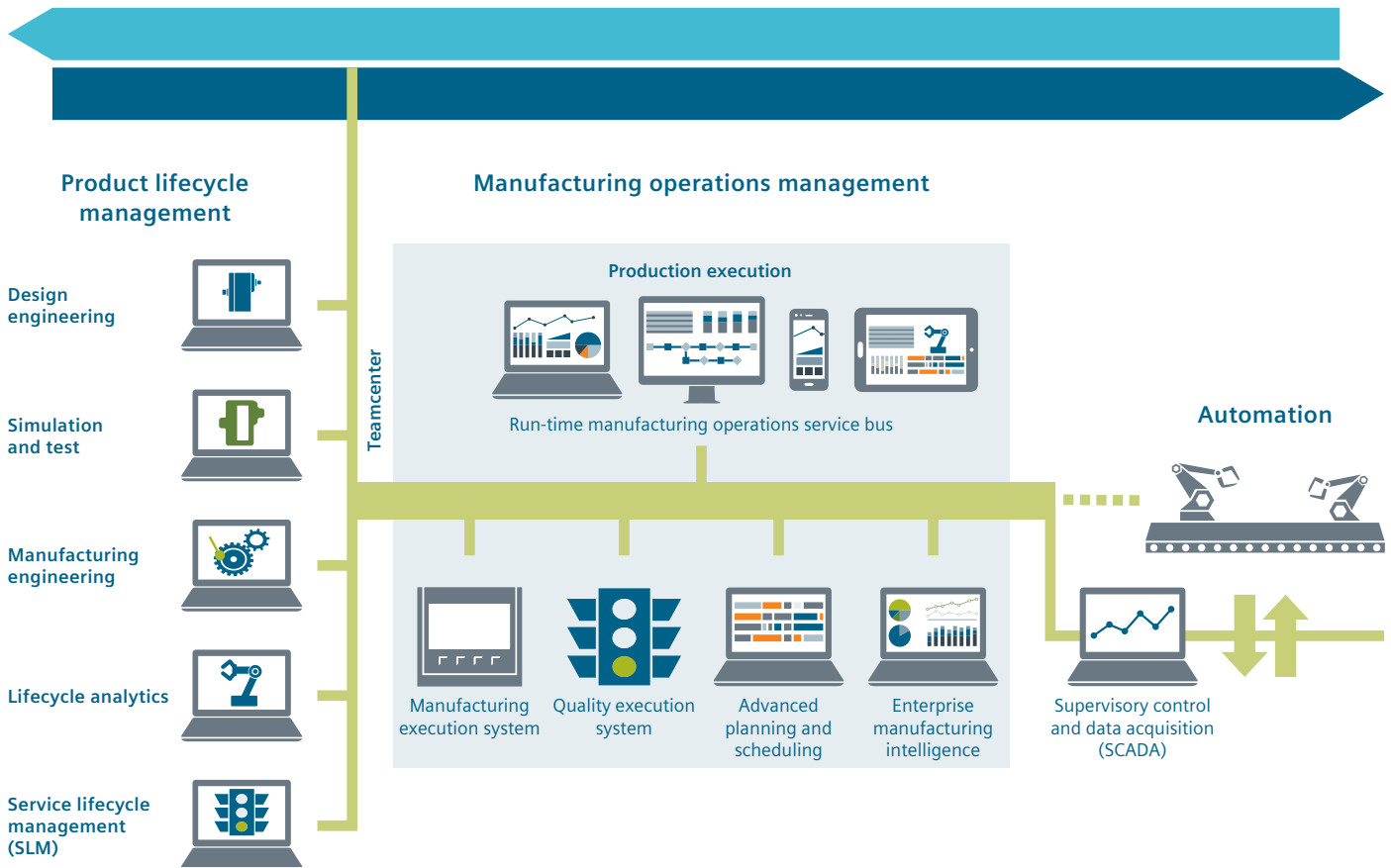| Ideation		Realization	Utilization
Virtual		**Physical**	
Bill-of-materials	Process planning	Production execution	Field performance
Product design	Production system	Automation	As utilized, As performs
As designed		As built	LA
PLM		MOM	
		TIA	
Collaboration backbone – Creating the digital thread			

Taking a platform approach

Manufacturing execution systems (MES) have been adopted at a consistent rate over the years, although there remains a high percentage of companies that linger in the planning stages of adoption. This is because the industry still takes a big-bang, project-based approach. As new solutions are deployed on the journey to Industry 4.0, they must live and grow alongside existing systems or replace them.

By taking a platform and application approach, manufacturing companies can implement a measured, incremental and layered process for moving from legacy systems that likely include both homegrown and existing packaged software to a next-generation platform solution.

Enterprise platforms today are used to manage the supply chain and product lifecycle processes without a consistent interaction with the manufacturing base. A platform built for Industry 4.0 must support all aspects of manufacturing operations, including enterprise resource planning (ERP), PLM and industrial automation, for a single coordinated enterprise. The platform must have the capability to completely digitalize and seamlessly integrate product and production lifecycles for flexible, scalable production processes that maximize your responsiveness to real-time manufacturing events.

Collaboration backbone

Product lifecycle management

- Design engineering
- Simulation and test
- Manufacturing engineering
- Lifecycle analytics
- Service lifecycle management (SLM)

Teamcenter

Manufacturing operations management

Production execution

Run-time manufacturing operations service bus

- Manufacturing execution system
- Quality execution system
- Advanced planning and scheduling
- Enterprise manufacturing intelligence

Automation

Supervisory control and data acquisition (SCADA)

Requiring unified data models across domains

In order for the digital twins to understand information communicated via the digital thread, data must be consistently defined and translated from one domain to the other. The virtual and real worlds are linked automatically by the manufacturing master data model (MDM) and the common plant model (CPM).

The technical domain will lead the development of the bill-of-materials (BOM) and the bill-of-process (BOP), the virtual twin of the product and virtual twin of the process, respectively, which will be maintained in one shared manufacturing master data model and authored in one environment for production planning and production execution. The physical domain will be represented with one common plant model virtually representing the physical assets and manufacturing capabilities (digital twin of the equipment). The digital twin then hosts the engineering configuration of the entire manufacturing space and represents its runtime model.

In addition, components of a holistic quality process must be seamlessly integrated, including critical characteristic definitions, control/inspection plans, corrective actions and complaints.

Manufacturing is executed in the physical world. The rise of MES on the factory floor means a manufacturer can collect and maintain a wealth of data on the production and form of physical products. In addition, this collection has progressed from being manually collected and paper based to being digital, collected by a wide variety of physical sensing technologies, including programmable logic controllers (PLCs), sensors and gauges, IoT devices, etc.

Real-time data that have been collected are then used to continuously update the virtual world. For instance:

- When an original equipment manufacturer (OEM) changes a line configuration during commissioning and/or production ramp up to update the common plant model

- When identifying issues in assembly production that impose a work instruction change during volume production to optimize process planning

- When as-built information with a quality evaluation of supplier parts is used to update the product structure

Updating the virtual world provides a more accurate representation of reality. This is the basis for finally improving the real-world version via simulation of the digital model, thus closing the loop.