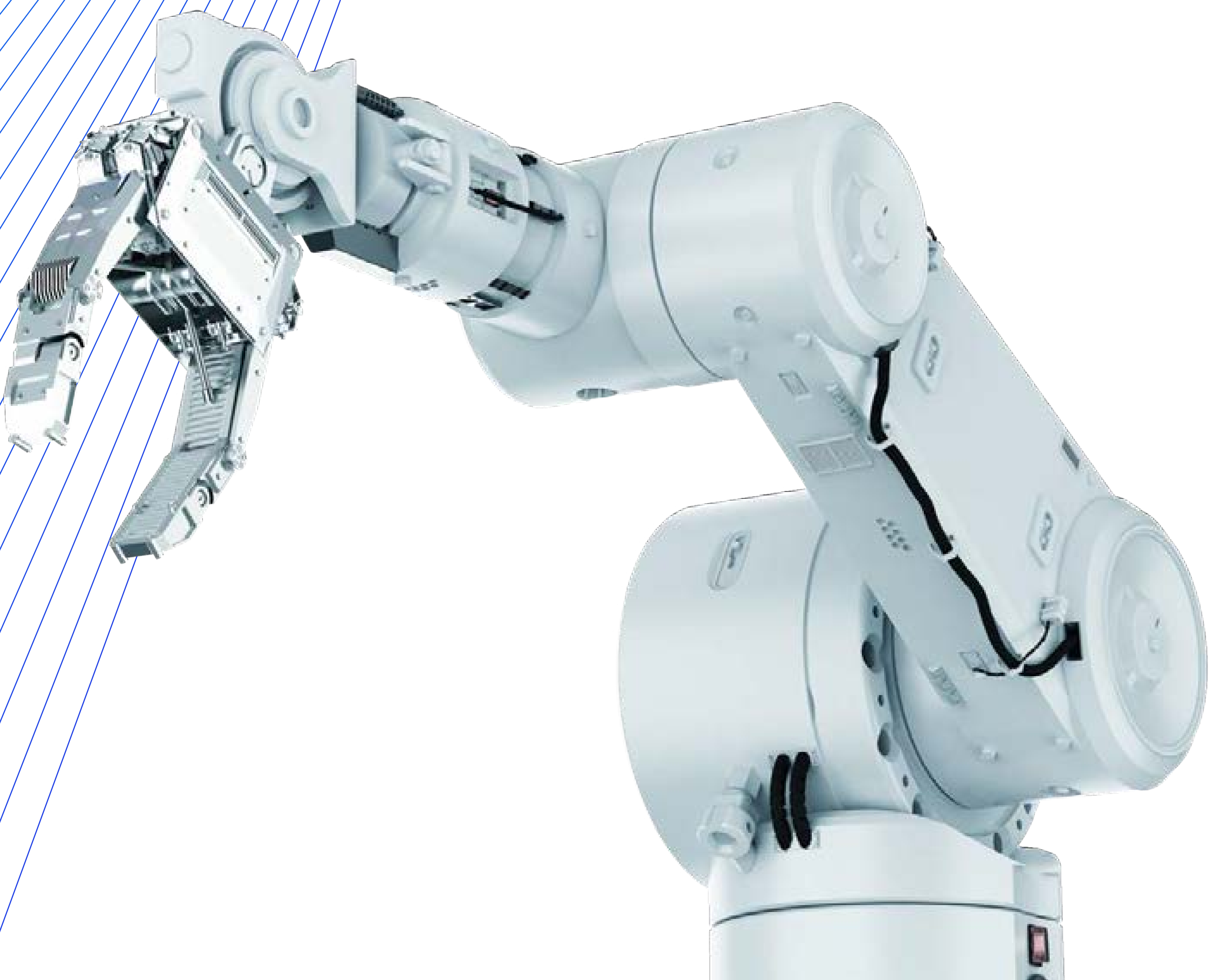
McKinsey & Company

Industry 4.0

Capturing value at scale in discrete manufacturing



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Executive summary

With an estimated value creation potential for manufacturers and suppliers of USD 3.7 trillion in 2025,[1] high hopes are set on Industry 4.0 to bring the next industrial revolution to discrete manufacturing. Yet, only about 30 percent of companies are capturing value from Industry 4.0 solutions at scale today. Approaches are dominated by envisioning technology development going forward rather than identifying areas of largest impact and tracking it back to Industry 4.0 value drivers. Further governance and organizational anchoring are often unclear. Resulting hurdles related to a lack of clarity regarding business value, limited resources, and an overwhelming number of potential use cases leave the majority of companies stuck in "pilot purgatory."

To provide a perspective on how to get "unstuck" and finally capture real value through Industry 4.0 in discrete manufacturing, our report illuminates two key questions: where to focus and how to scale.

Drawing on the latest McKinsey research and a series of interviews, we arrived at the following key insights:[2]

I. Where to focus – factory archetypes and industry-specific key value drivers

Three factory archetypes define the productivity imperative, which establish the relevant set of key value drivers capturing impact at scale:

— Small-lot manufacturing aims to remain efficient down to lot size 1. Here, the key value drivers are an integrated product data model from engineering to commissioning, digital worker enablement, and data-driven OEE optimization.

— Mass-customized production focuses on enabling a certain degree of product variance while upholding high throughput and consistent quality. To this end, Industry 4.0 value is in closed control loops (enabled by sensor-based, in-line quality inspection), flexible routing, scheduling, load balancing and performance management, and the extension of automation to final assembly.

— High-volume production aims for fully automated production and maximized OEE with flexibility to adapt to the product mix. Industry 4.0 key value drivers are closed control loops through sensor-based in-line quality inspection, conquering the remaining domains of manual labor through automation and traceability.

— Industry 4.0 target pictures, value drivers, and case examples for machinery (small-lot manufacturing), automotive (mass-customized production) and consumer electronics (high-volume production) provide hands-on examples of each archetype (please see Table 1 for an overview on where to find specific case examples).

II. How to scale – focusing on value, mobilizing the organization, and innovating the infrastructure

Three key principles guide Industry 4.0 value capture at scale:

— Think value-backward, not technology-forward. A focus on key value drivers and a compelling Industry 4.0 vision are crucial.

— Be people centric, not tool centric. Backed by top-management support, Industry 4.0 transformations need to focus on capability building and be pursued as a strategic organizational endeavor. As such, they should be informed by a clear business leadership mindset, not just by an engineering or IT process.

— Innovate the infrastructure towards an integrated technology stack and a clear target picture. Infrastructure should enable local operations before scaling globally, as many use cases deliver value already through on-premise infrastructure.

1 "The Next Economic Growth Engine Scaling Fourth Industrial Revolution Technologies in Production," WEF/McKinsey white paper, 2018
2 Three steps were taken in order to derive insights for this report; drawing on the latest McKinsey research from a global manufacturing survey with the discrete-manufacturing community, conducting a series of in-depth interviews with manufacturing practitioners across industry verticals and Industry 4.0 key value levers, and syndicating insights from structured interviews from our world-leading industry operations experts.

Table 1

Overview of key value drivers and case examples for analyzed industries

Industry	Key value driver	Case example	Page
Machinery	Integrated product data model from engineering to commissioning	ANDRITZ Ritz implements seamless dataflow from CAD/CAM to machine tool controllers	18
	Digital enablement of workers	Industrial equipment manufacturer boosts efficiency through “shop floor to top floor” digital enablement	20
	Data-driven OEE optimization	DMG Mori technology helps Martin-Baker to achieve 80% OEE in high-variant machining	22
Automotive	Flexible routing, scheduling, and load balancing	Porsche deploys flexible AGV-based assembly line to optimize its electric vehicle production	28
	Closed control loops through sensor-based in-line quality inspection	Ford automates quality control through camera-based in-line quality inspection	30
	Extension of automation to final and pre-assembly	Bosch increases end-of-line parts inspection efficiency through flexible and collaborative robotization by Rexroth	32
Consumer electronics	Conquering remaining domains of manual labor through automation	Global electronics contract manufacturer introduced robotic automation solutions to reduce its labor cost in selected areas by 80%	40
	Closed quality loops through sensor-based in-line quality inspection	Samsung uses cutting-edge 3D vision scanning to tackle growing demand and strict quality standards for LCD panels	42
	Traceability	Seagate plans to utilize IBM Blockchain and electronic fingerprinting to track supply chain for hard drives	44

Starting point – Industry 4.0 as the next s-curve in discrete manufacturing

Industry 4.0, or the fourth industrial revolution, is expected to lead operations to the next s-curve of productivity. McKinsey's recent research with the World Economic Forum puts the value creation potential of manufacturers and suppliers implementing Industry 4.0 in their operations at USD 3.7 trillion in 2025.[3]

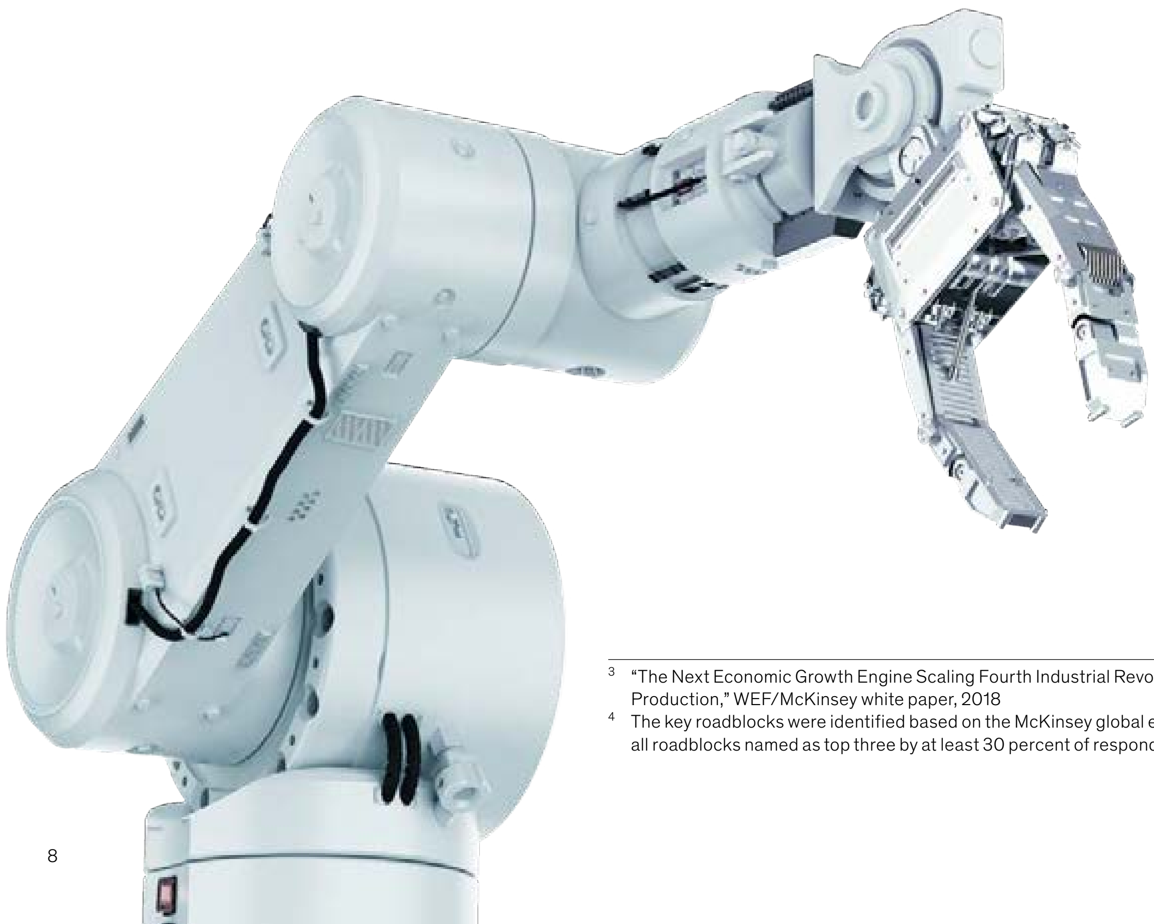
Among its several key findings (see page 9), our global manufacturing survey reveals that 68 percent of companies see Industry 4.0 as a top strategic priority today. How fast Industry 4.0 has moved into the focus can also be seen by running a Google trends analysis. The search term "Industry 4.0" is likely to surpass "lean manufacturing" in 2019, despite being almost nonexistent prior to 2014.

Given this high degree of attention on Industry 4.0, it is no surprise that 70 percent of companies have already started to pilot Industry 4.0 solutions. What may be surprising, however, is that at the same time, only 29 percent of companies are capturing value from such solutions at scale, with the rest being stuck in "pilot purgatory." But why exactly is the capturing of value at scale through Industry 4.0 lagging in so many companies?

To answer this question, let us briefly refer to what the McKinsey global expert survey reveals about key roadblocks to the deployment of Industry 4.0 solutions at scale – and to what winners say about how to overcome them:[4]

USD 3.7 trillion

value creation potential in 2025



3 "The Next Economic Growth Engine Scaling Fourth Industrial Revolution Technologies in Production," WEF/McKinsey white paper, 2018

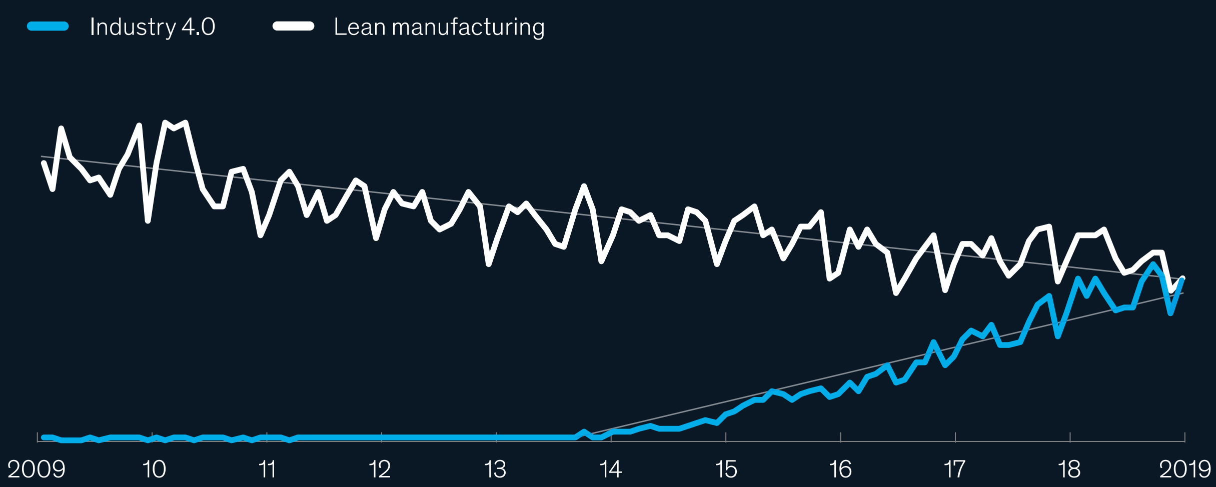
4 The key roadblocks were identified based on the McKinsey global experts survey and reflect all roadblocks named as top three by at least 30 percent of respondents.

30% Industry 4.0 value capture at scale

Industry 4.0 becomes the new productivity imperative of discrete manufacturing

Interest over time[1]

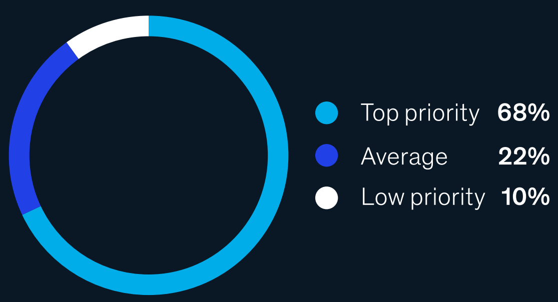
Google trend score analysis



While Industry 4.0 is a strategic priority, value capture at scale is lagging behind

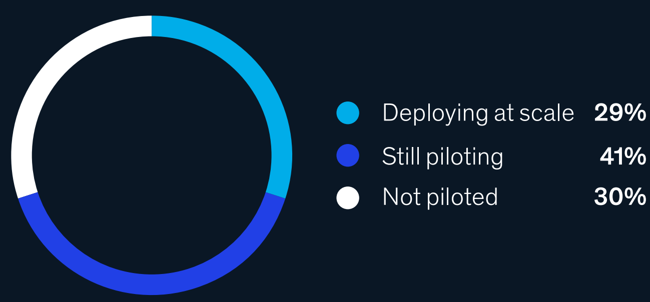
How much of a priority is Industry 4.0 on your company's strategic agenda?[2]

Percent



Status of Industry 4.0 solutions[2]

Percent

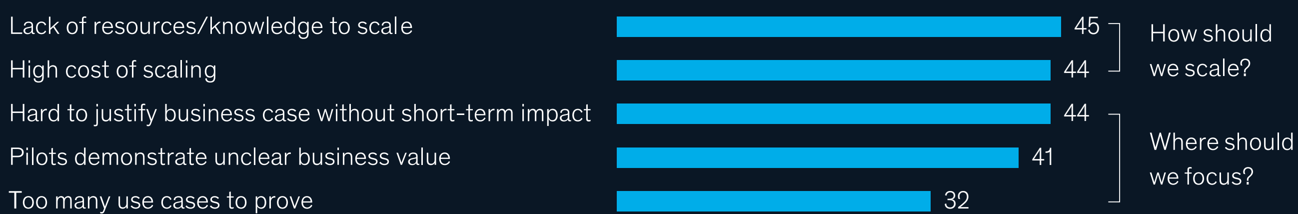


To unleash the power of Industry 4.0, key roadblocks need to be overcome

Top 5 roadblocks preventing the move from pilot to rollout[3]

Percentage of respondents choosing the reason as 1 of their top 3

Underlying questions



1 Comparison of Google trend score for global interest in "Industry 4.0" and "lean manufacturing," trends.google.com
2 "The Next Economic Growth Engine Scaling Fourth Industrial Revolution Technologies in Production," WEF/McKinsey white paper, 2018
3 Based on McKinsey global manufacturing survey

Lack of knowledge and resources to scale

While this issue is often mentioned in the context of not enough budget or people being committed to Industry 4.0 initiatives, the underlying challenges are often more complex. For example, the introduction of new tools as part of an Industry 4.0 transformation will only deliver value if the organization is trained and enabled to leverage the tools as part of the core value creation engine. However, the deployment of new tools often is too tech or IT focused and does not put enough emphasis on capability building in the existing operations community (e.g., including lean and Six Sigma specialists). However, it is precisely these operations experts who could be the change agents and catalysts who complement the set of digital tools with their vast domain and process knowledge to ensure value capture. In addition, unclear governance structures and a lack of anchoring of Industry 4.0 initiatives in the organization lead to a perceived lack of knowledge and dilute the existing resources.

What winners say:

"Succeeding in Industry 4.0 asks for (far) more than deploying new IT tools; it requires no less than a tech-enabled organizational transformation of operations"

High cost of scaling

Companies hesitate to make high upfront manufacturing IT investments (and also see significant risks) in connecting their entire manufacturing footprint to an IIoT cloud. Many fail to realize that often, on-premise solutions that scale through a site-by-site rollout can already deliver a high percentage of the business value at stake, with only a few use cases actually requiring that the shop floor be connected to an off-premise cloud.

What winners say:

"Capture value locally and be pragmatic when scaling! Industry 4.0 requires more than having all data stored in the cloud"

Hard to justify the business case without short-term impact

Industry 4.0 use cases often require investments into new technology, which do not amortize in the same year. However, the upfront investments can often be minimized by applying the minimum viable product (MVP) approach, i.e., thinking of the smallest possible implementation while still delivering a relevant business value in a certain area. The MVP's ROI often comes within months and allows companies to prove the economic potential of the use case as well as to run build-measure-learn cycles to maximize impact. With this de-risking approach, the full-scale rollout can be backed by a clear business case often with much shorter ROI timelines and more targeted investments than originally foreseen.

What winners say:

"Think big, start small, scale fast: de-risk investments into Industry 4.0 through a minimum viable product approach"

Pilots demonstrate unclear business value

In Industry 4.0 transformations, easy-to-implement pilots are often at the fringes of the operation's key value creation processes. It is also typical to see pilots that leverage a "fancy" technology get chosen in the first wave of implementation. While these choices limit the potential implementation risk and may lead to inspiring applications, they can also limit the contribution that such use cases can make to improving the P&L and obscure the business value created. Taking a "technology-forward" approach instead of an "impact-backward" selection of Industry 4.0 solutions can thus lead to pilots demonstrating unclear business value.

What winners say:

"Before embarking on any new pilot, make a thorough estimate of the potential P&L impact and define what success looks like"

Lack of focus due to large number of use cases

In many cases, companies have a plethora of use case ideas identified yet struggle to quantify and prioritize the top value drivers to pursue. Facing a long list of use cases all perceived as equally important and with limited resources to pilot the use cases on the list, many companies refrain from seriously deploying use cases at scale, seeing the long list of potentially promising ideas not yet tested.

What winners say:

"Value-backed prioritization is key to keeping pilots focused, and only focus will lead to success"

These findings regarding opportunities and challenges lead us to two sets of guiding questions identified as key to capturing value at scale through Industry 4.0 in discrete manufacturing. We cover them in the main chapters of this report:

— Where to focus: What are the most relevant Industry 4.0 value drivers, differentiated by factory archetype, to capture value at scale?

— How to scale: What is required to enable the organization to generate value at scale from key value drivers, and what role does IT infrastructure play?

I. Where to focus – factory archetypes and industry-specific key value drivers

Analysis of the barriers to the at-scale deployment of Industry 4.0 solutions suggests that identifying where to focus is one of two key topics for discrete manufacturing companies to address. For the many companies that are lost in the plethora of use cases and for whom pilots have not established a clear business value, focus – especially on key value drivers – is desperately needed.

However, creating a value-backed perspective on Industry 4.0 requires a granular approach, as pain points and value drivers in discrete manufacturing greatly differ by industry and even by company. Thus, there is no one-size-fits-all Industry 4.0 solution for discrete manufacturing. To cope with this complexity and provide meaningful guidance on which Industry 4.0 key value drivers are especially relevant for which discrete manufacturing industry, we will first identify factory archetypes within discrete manufacturing and then discuss the key value drivers of three specific industries, one representing each archetype, in greater detail in the following subchapters. This helps companies to identify the right focus areas to capture value at scale.

We see two main dimensions that differentiate factory types with regard to their Industry 4.0 key value drivers: number of variants produced in a factory and average lot size. Along these dimensions, we have identified three factory archetypes representing different combinations of measurements (Exhibit 1).

3 factory archetypes help to identify the specific productivity imperative and related key value drivers

Small-lot manufacturing

These factories face the productivity imperative of remaining efficient down to small lot sizes or even lot size 1. The factories of this archetype produce a large variety of products in small lot sizes, i.e., almost always less than 50 and in the most extreme case, in lot size 1. Products are often specifically engineered for each order, sometimes based on a modular architecture but often fully customized with frequently-occurring design changes. Small-lot manufacturing factories characterize the machinery,[5] aerospace, shipbuilding, and rail equipment sectors. To some degree, material-handling equipment manufacturers are also characterized by this archetype, as many (e.g., warehouse system suppliers) produce highly customized orders.

Mass-customized production

These manufacturers face the productivity imperative to enable mass customization, maintaining high throughput and consistent quality. Factories of this archetype typically produce large volumes of products that share a common core but may be customized to a certain degree, creating production process sections with repetitive larger lots (e.g., automotive press shop) and sections of high product variance (e.g., automotive final assembly). The customers of mass-customized production factories typically customize their products based on a predefined set of configuration options, which can be integrated in a common modular architecture. Mass-customized production type factories are typical in the automotive industry, automotive Tier-1 suppliers and, to some extent, in the truck, bus, agricultural, and construction equipment sectors. Industrial equipment manufacturers – where factories simultaneously have large production volumes and accommodate an ever-increasing number of variants – run mass-customized production type factories as well.

High-volume production

High-volume manufacturers follow the productivity imperative to fully automate production and maximize OEE while upholding a certain flexibility to adapt to a changing product mix. Production volumes per lot are very large, and customization

5 Including machine tools, food, beverage, and tobacco machinery, packaging machinery, pulp and paper machinery, textile machinery, printing machinery, semiconductor machinery, rubber and plastics machinery, and woodworking machinery

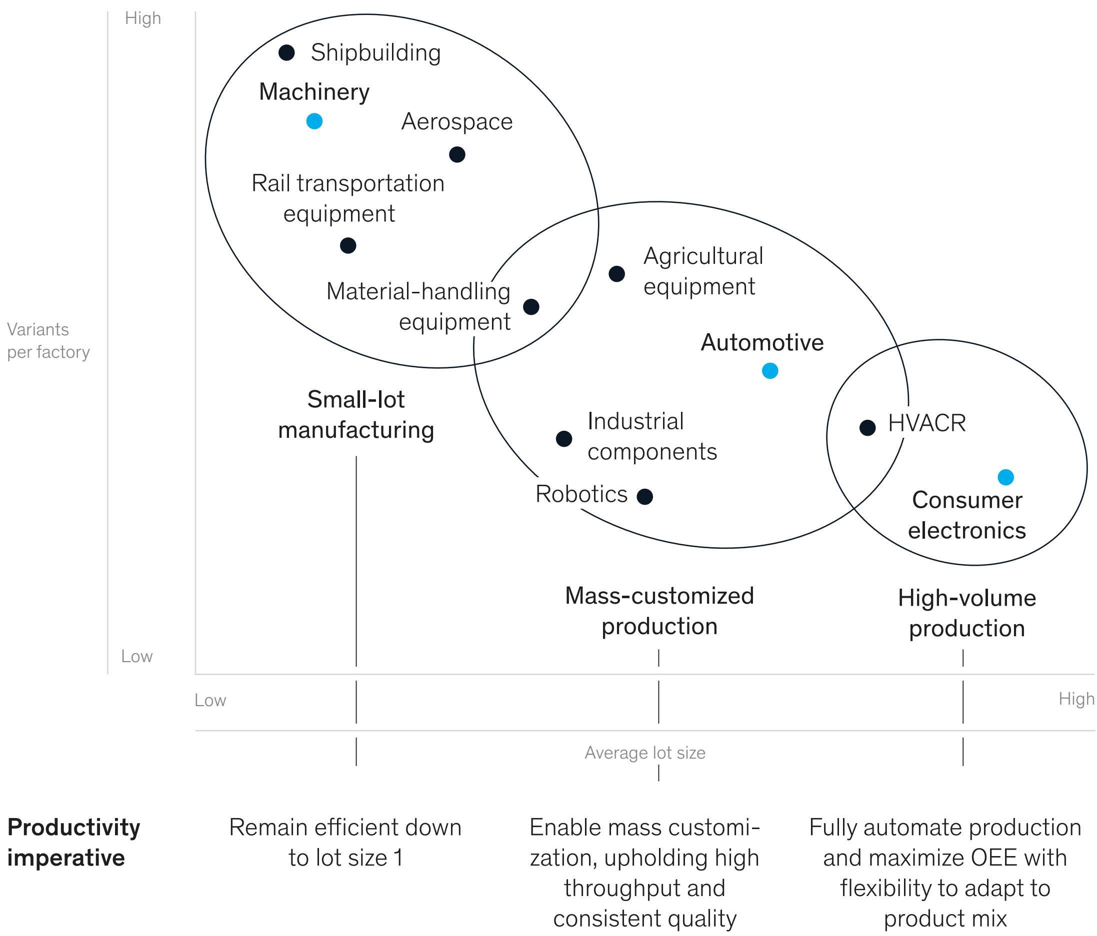
is either very limited or nonexistent. High-volume production factories can typically be found in the electronics manufacturing industry and related production environments (e.g., at electronics-focused automotive suppliers) as well as, to a certain degree, in the heating, ventilation, air conditioning, and refrigeration-manufacturing sector.

The three identified factory archetypes and their corresponding productivity imperatives represent the various discrete manufacturing industries.

We selected typical representatives for each archetype for our deep dive discussions, namely the machinery, automotive, and consumer electronics industries. Besides being of significant size, they are also positioned rather squarely within their factory archetype clusters, i.e., far from the overlaps between archetypes and far from each other in terms of number of variants and their productivity imperatives. In the following deep dives, we derive detailed Industry 4.0 target pictures for each industry, taking into account both archetype characteristics and specific industry trends. We list and discuss key value drivers and provide case examples of successful implementations.

Exhibit 1

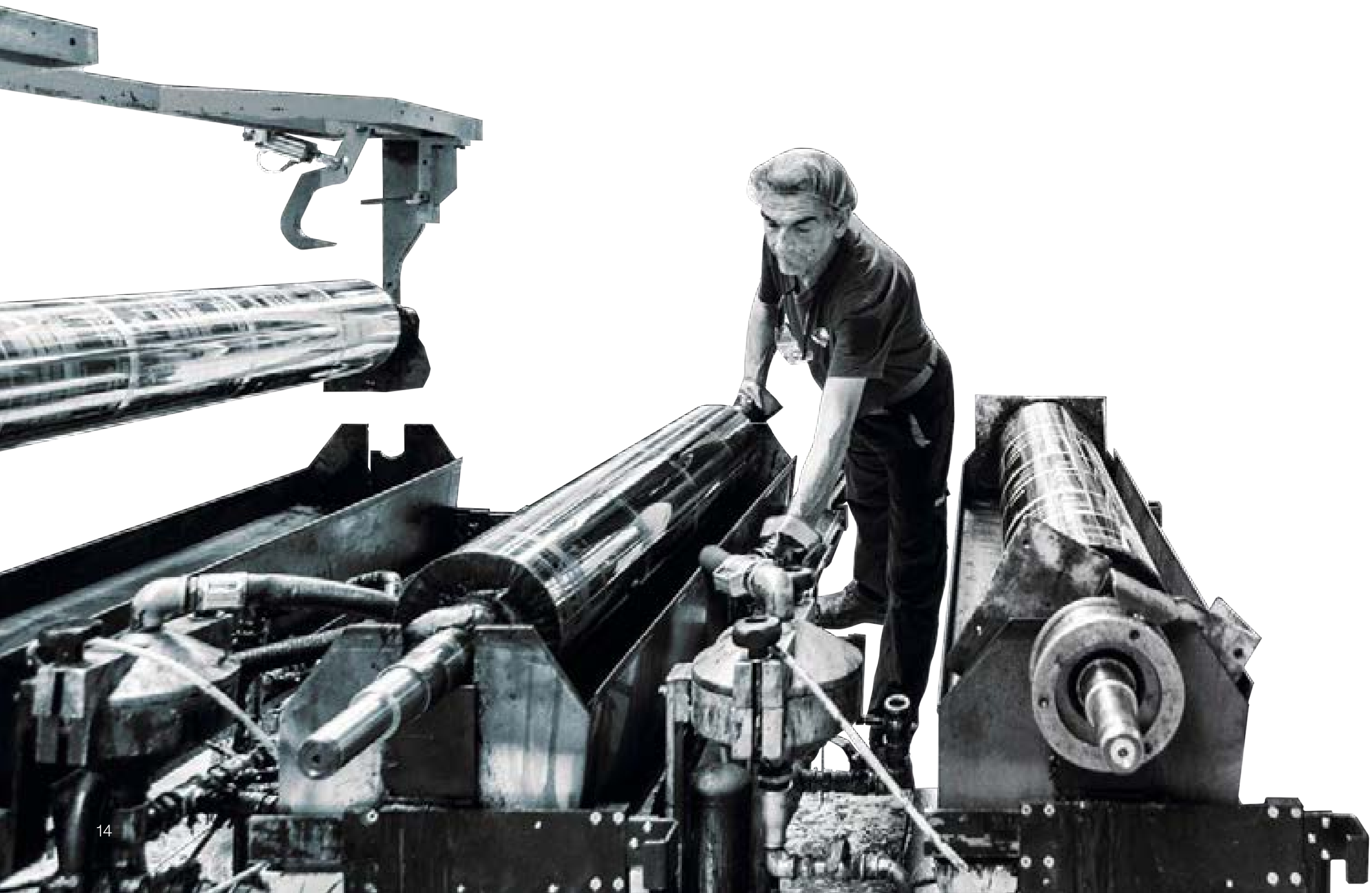
Overview of the 3 factory archetypes in discrete manufacturing, their productivity imperatives, and representative industries



I.I Machinery

Key value drivers and target picture in a "small-lot manufacturing" industry

Production in the machinery industry has long followed a traditional manufacturing approach, focusing on flexible factory layouts and the craftsmanship of skilled specialists. In recent years, this approach has been enriched by elements of lean manufacturing (e.g., Kanban, Six Sigma), selective automation, and the selective integration of software systems on the shop floor.



Machinery industry trends defining key value drivers

We identified three major industry trends that reinforce the industry's productivity imperative of "remaining efficient down to lot size 1" (see Exhibit 1 on page 13) and thus will have strong implications for the future operations of machinery companies:

High demand volatility

Economic analysis shows that the machinery industry is seeing a level of demand volatility much higher than that of their customer industries (i.e., 5 to 20 percentage points higher between 2014 and 2016, depending on the machinery sector[6]). To cope with the high demand volatility, many machinery manufacturers leverage a high percentage of temporary workers to cover demand peaks. These workers are often less skilled or experienced than the rest of the staff, leading to higher training requirements and, in some cases, quality and productivity challenges.

Demand shift toward developing markets

A representative joint study with the German Mechanical Engineering Industry Association (VDMA) reveals a shift of demand away from developed and toward developing markets, especially to Asia, as a trend affecting more than two-thirds of the industry.[7] This shift leads to higher currency exchange rates, higher logistics costs, and tariff-related risks if the current manufacturing footprint is maintained. Many machinery OEMs are thus moving to local-for-local strategies, globalizing their footprint and supply chain. However, this globalization increases the complexity of the supply chain and also the commissioning operation. Furthermore, it makes parity and consistency of quality and productivity between best-cost countries and high-cost countries more challenging.

Increasing demand for customization and integration

More than two-thirds of machinery manufacturers are experiencing an increasing demand for highly customized and fully integrated system solutions.[8] The resulting increase in complexity in system design as well as assembly and commissioning can only be partially compensated by standardization and modularization efforts of the manufacturers.

Accordingly, the following three value drivers related to Industry 4.0 are especially relevant for the machinery industry:

— An integrated product data model from engineering to commissioning enables efficient production on sites throughout a global footprint and supply chain as well as an efficient path to manage increasing product complexity driven by the demand for customized system solutions.

— The digital enablement of workers becomes a key value driver when faced with an increasing number of temporary workers and an overall decline in the skilled workforce.[9] Related solutions can either help to rapidly train employees or to break the tasks at hand into small steps that are easily manageable for unskilled laborers.

— Data-driven OEE optimization can generate significant value in cases where companies generate a significant value add to their product through internal machining. This value driver is hence only relevant to the heavy operations side of machinery.

The resulting factory of the future target picture on page 16 shows how the three key value drivers mentioned above break down into tangible, value-driven use cases that closely interact in the machinery factory of the future. In the following, we will detail the key value drivers and provide examples of successful implementation.

6 Based on selected industry examples in aeroderivative gas turbines, chewing gum machinery, ceramic tiles machinery, and lithium ion battery manufacturing machinery markets, and drawing on: BP Statistical Review of World Energy 2016; Euromonitor; The Tile Council of North America; VDMA roadmap battery production equipment 2030; company annual reports.

7 In line with top trends identified in VDMA-McKinsey study, "The Future of German Mechanical Engineering," 2015

8 In line with top trends identified in VDMA-McKinsey study, "The Future of German Mechanical Engineering," 2015

9 While the VDMA-McKinsey study, "The Future of German Mechanical Engineering," 2015, did not reveal that this trend affects a majority of machinery companies, it was perceived as the number two risk for the industry.

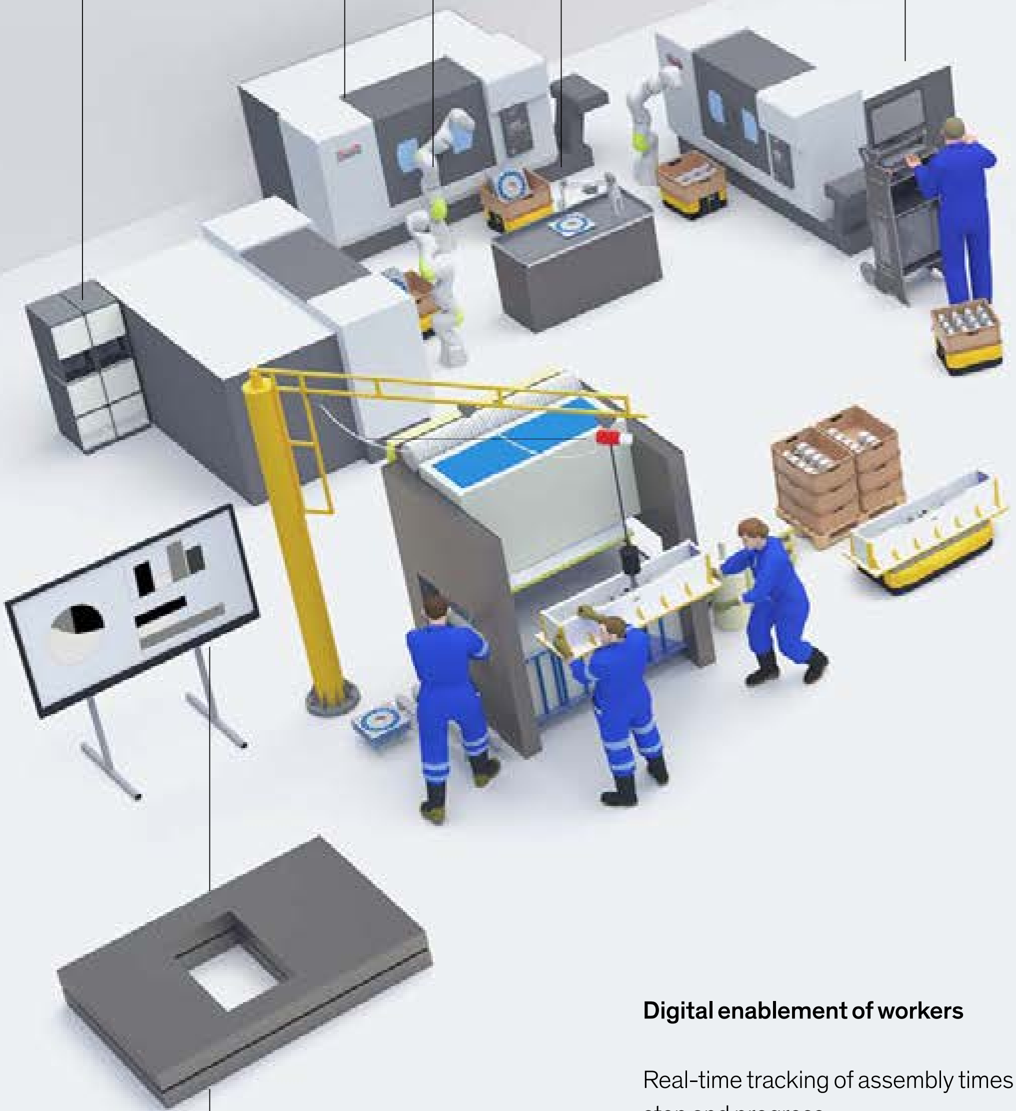
Machinery factory of the future target picture

Data-driven OEE optimization

Automated machine setup and feeding

Digital process optimization based on machine and quality data

Manufacturing IT integration for digital performance management for critical bottleneck machinery



Digital enablement of workers

Real-time tracking of assembly times per step and progress

Digital documentation, drawings, trouble-shooting guides, and checklists

Digital work orders containing detailed task description and sequence

Integrated product data model from engineering to commissioning

Integration of quality data into digital tool chain

CAD/CAM tool chain allowing offline NC programming parallel to machining

Engineering and design software supplying latest information to shop floor

Virtual commissioning allowing for direct commissioning at customer site, eliminating prior in-house build-up, quality testing, and disassembly

Machinery key value driver – integrated product data model from engineering to commissioning

Status quo

During the last decade, a digital tool chain integrating design and engineering systems (CAx/CAQ/PLM) has emerged and is being implemented in many machinery companies. The adoption of these systems is helping companies to better handle the complexity induced by the demand for integrated system solutions. While an increasingly integrated digital tool chain is becoming more common in the engineering and design stages of value creation, the full integration of the product data model – down to the shop floor and throughout the supply chain and life cycle – is not yet the norm. Today, interruptions of the digital dataflow, e.g., through tool incompatibility with existing machines or simply a lack of training or digital shop floor devices, are still the rule. As a result, paper-based work orders and assembly instructions remain commonplace on the shop floor and in assembly, and benefits from integrated product data models, such as the automated generation of NC/CNC code in machining, are only partially captured.

A fully integrated product data model reduces machine idle times and boosts labor productivity

Scope of action

An integrated data model from engineering to commissioning across systems (e.g., CAD, CAM, CAQ, PLM) enables the seamless dataflow from the design phase through assembly and commissioning. Furthermore, integration lays the foundation to generate Industry 4.0 value at scale throughout the manufacturing and assembly processes as well as the whole product life cycle (e.g., servicing).

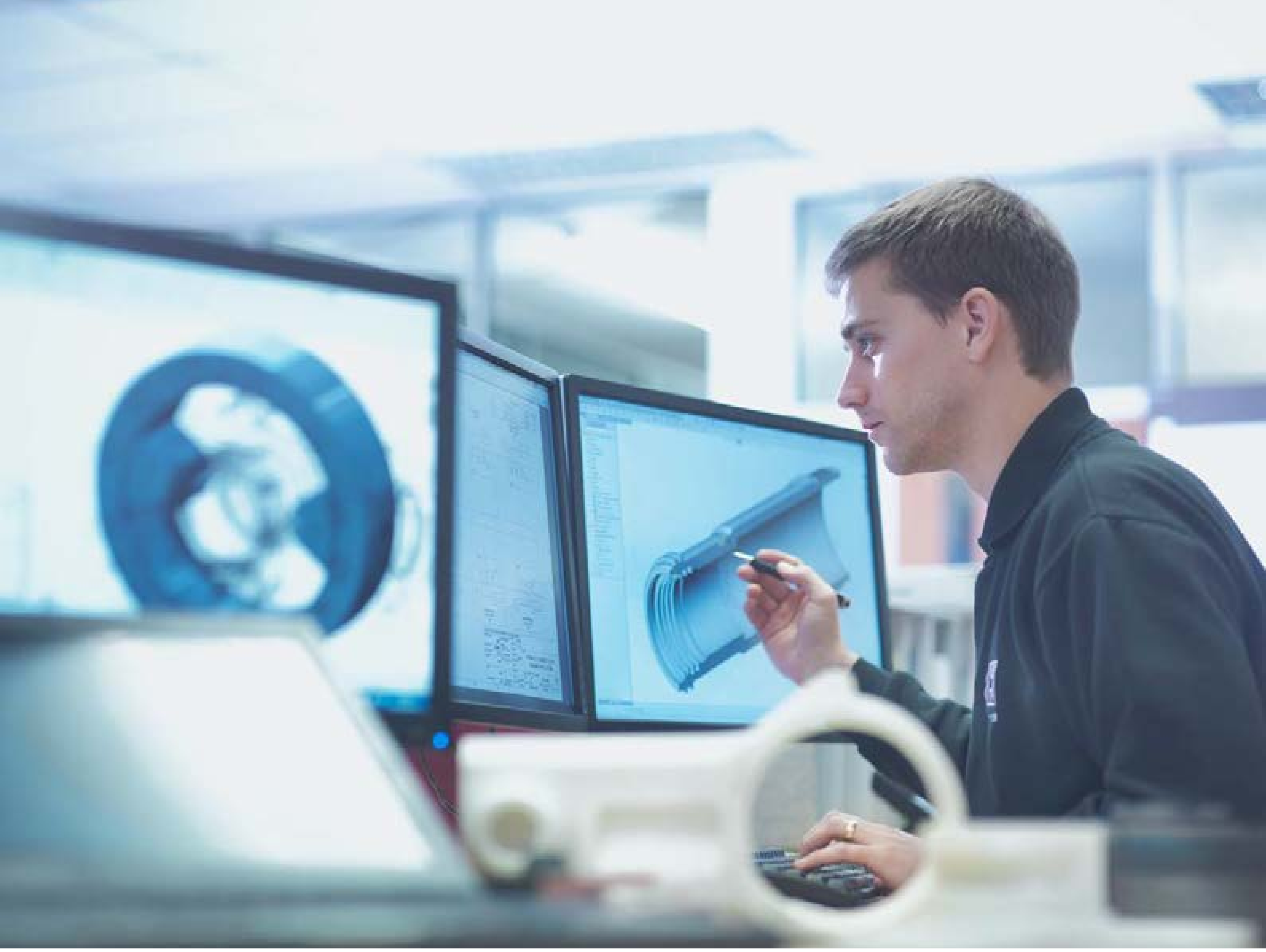
Process-wise, the fully integrated engineering and design software supply the latest information to the shop floor, which ensures up-to-date information even in the case of design changes, thus reducing manufacturing and assembly errors. For example, in machining, an integrated CAD/CAM tool chain allows for automated NC/CNC program generation and verification in parallel to machine operations. The integration of quality data into the digital workflow creates a single point-of-truth dataset. The resulting PLM model with integrated high-precision metrology data allows for, for example, the simulation of fittings and machine parameter adjustments of housing parts. This reduces manual rework in later assembly steps, while at the same time increases precision.

The resulting transparency on product data across all stages via, for example, a digital twin, also allows machinery manufacturers to move toward digitalized commissioning. Furthermore, an integrated product data model enables direct commissioning at the customer site, skipping in-house line-up and internal testing as well as disassembly, which significantly reduces required work hours and shortens lead times.

Benefits

A fully integrated product data model reduces machine idle times and boosts labor productivity in machining areas through automated offline NC/CNC code generation. This model also frees up often critical machine control programming capacity by increasing programming efficiency.

The digital information flow that integration enables allows for shorter lead times, design change implementation from machining to commissioning, and significantly reduced labor costs during the assembly and commissioning stage.



Case example:
ANDRITZ Ritz implements seamless dataflow from CAD/CAM to machine tool controllers
The implementation from Siemens Teamcenter enables ANDRITZ Ritz to seamlessly transfer project information from manufacturing planning to production. On the shop floor, PC workstations are connected to machine controls via a serial interface or Ethernet. Machine operators gain role-specific access to released data. For each job, only the information that is needed is shown. Depending on the job complexity, simulation data, CAM parts, CAD models, pictures, videos, and work plans may supplement the default information of NC data, shop floor drawings, and tooling sheets.

Due to the direct access to PLM information on the shop floor, the machines' idle times are significantly reduced, and the operators are able to effectively minimize variation in quality and manufacturing errors.

Direct access to PLM information on the shop floor

Machinery key value driver – digital enablement of workers

Status quo

At present, workflows in assembly and intralogistics are largely paper based, which makes it difficult to have accurate and up-to-date information on the progress of work orders, the location of parts, and sometimes even the assembly sequence and steps for a specific order – an issue especially relevant in low-volume environments when no two products are alike. In addition, engineering changes are often communicated to the shop floor with significant delays, leading to workers executing production and assembly tasks based on outdated work orders. This lack of transparency leads to errors and delays in the assembly process, causing rework and longer lead times within the factory and in the commissioning process at the customer site.

Furthermore, fully paper-based workflows inhibit process improvements and performance management. Capturing and preparing paper-based information for performance analysis is a highly time-consuming task. Thus, data capture for process improvement analysis is often limited, and real-time performance management is impossible due to time delays through processing.

Early focus on the usability and the acceptance of the digital solution by the workforce are key to success

Scope of action

Digital worker enablement typically combines the switch from paper-based to digital information flows with an increase in the use of digital devices on the shop floor and in commissioning. Switching from paper-based to fully digital workflows and information displays that are tailored to the manufacturing environment (e.g., rigid tablets, digital terminals) can give companies a more accurate read on time-critical information. Specifically, digital work orders and assembly instructions containing detailed task descriptions and sequences based on the latest design revision are accessible from the shop floor at all times.

Digital resources include work instructions, drawings, troubleshooting guides and checklists that support assembly workers in their own factory and during commissioning at the customer site. In addition, digital documentation of work progress enables real-time work-in-progress tracking and performance management. For example, based on the actual work time required for each step, work content can be much better compared to assembly standard times and even dynamically reallocated depending on the skill or experience level of the worker. Furthermore, work steps where the actual times show a large standard deviation can be explicitly reviewed and optimized, as this is an indicator that problems are occurring. Thus, digital worker enablement solutions take the lean approach to the next level.

Critical for the success of digital worker enablement as a key Industry 4.0 value driver is the early focus on the usability and the acceptance of the digital solution by the workforce. This is the case because only a user-centric approach will lead to the digital content actually being used on the shop floor. Key aspects to be considered include: rigidity of devices, usability with common safety equipment, comfort while wearing, battery life lasting for at least a full shift, etc. Along with the focus on usability, enabling the workforce to generate and apply the digital content is key, as without proper training, much of the potential may remain untapped.

Benefits

Digital workflow tools enable real-time tracking of assembly times and progress. This level of access to to-the-minute information enables the early rebalancing of capacities and timely detection of delays. Together, this increases labor productivity and reduces lead times.

Case example:
Industrial equipment manufacturer boosts efficiency through "shop floor to top floor" digital enablement

TATA codeveloped an end-to-end visibility solution in two assembly plants of a Swedish industrial tools and equipment manufacturer. The solution created transparency throughout both the inbound and the outbound enterprise supply chain.

Custom applications of the solution included integration with ERP, a shop floor control system, and third-party logistics. TATA implemented key functionalities comprising, among others, order management, kitting, electronic Kanban, traceability, torque and test data logging, digital work instructions, barcode printing, and real-time updates via dashboards.

The bottom-line results of this connectivity solution were a 30 percent efficiency gain in product planning and a reduction in subassembly WIP time from three days to four hours.

30%

efficiency gain

Status quo
Machining OEE optimization typically becomes a key value driver in machinery manufacturing when the machinery park is capital intensive, highly utilized, or a bottleneck to the rest of the production. In contrast, if machining is largely outsourced and the focus lies on assembly, machining OEE optimization is of less importance.

Data-driven OEE optimization aims to use advanced analytics to identify the root causes of OEE loss

Scope of action
Data-driven OEE optimization aims to use advanced analytics to identify the root causes of OEE loss within the three OEE drivers of availability, performance, and quality and to identify countermeasures to these root causes.

The first step toward data-driven OEE optimization is to create transparency on the current OEE across the manufacturing site as a starting point for later optimization. Capturing detailed OEE information is thereby key. OEE measurement needs to be backed with OEE category-specific event tracking and time series measurement (e.g., changeover times versus waiting times, unplanned stops, including reasons) to allow for a drill-down on the drivers of OEE and root cause analysis of any failure mode occurrence. Typically, this tracking builds on an integrated manufacturing IT, enabling digital event tracking and the integration of event data with information from higher-level systems (e.g., supply chain information, quality data, shift scheduling).

As a second step, a root cause analysis based on the logged event data and failure modes is conducted for all OEE loss drivers. Advanced-analytics-backed correlation analysis can reveal root causes for OEE loss based on an integrated dataset, combining information on relevant root cause areas (such as supply chain information, tool and equipment data and maintenance schedules, operator training level and experience, components' design features). To focus and prioritize root cause analysis efforts, OEE benchmarks across shifts, manufacturing sites, and potentially with other noncompetitive firms with similar machine operations can serve as a starting point.

Benefits
Machining OEE optimization reduces production cost by lowering machine hourly rates through productivity increases and the reduction of lead times, in cases where machining processes lie on the critical path.

Case example:
DMG Mori technology helps Martin-Baker to achieve 80 percent OEE in high-variant machining

Martin-Baker manufactures aircraft ejection seat systems and spare parts for 56 different aircrafts, leading to more than 500 parts being produced in batch sizes of 5 to 15 in their in-house machining department. Keeping OEE high has been a tremendous challenge, given the required flexibility and variance.

Based on an in-depth analysis of the manufacturing process and OEE drivers, DMG Mori supported Martin-Baker in reaching 80 percent OEE in a 24/7 manufacturing operating model with one manned shift and two unmanned shifts. Traditional pallet-based machine loading automation solutions and an integrated software solution are able to a) monitor and detect tool wear, tools blockage, and missing material and b) automatically adjust job sequences and send failure notices to the central production monitoring control room. Together, these solutions helped to bring OEE up to 80 percent in the critical machining areas.

OEE up to

80%

I.II Automotive

Key value drivers and target picture in a "mass-customized production" industry

Automotive manufacturing led the adoption of modern production principles, such as lean or Six Sigma, and the underlying production systems are designed to cope with the complexity of mass-customized products. The industry, however, is rapidly changing, and there are three trends that require automotive manufacturing to further transform.

Automotive industry trends defining key value drivers

Consumers' demand for greater personalization

Consumer-driven demand for greater personalization options and more platform derivatives per segment increase the number of variants and lead to shorter lead times, requiring more flexibility, especially in final assembly.

Stricter emission standards

Furthermore, stricter emission standards in the case of combustion vehicles and the high weight contributions of batteries in the case of BEVs will require the extended use of lightweight materials. Consequently, the use of lightweight materials will increase the use of new joining technologies, such as riveting and adhesive joining. In addition, the shift to BEVs and PHEVs will require a major change in the overall value creation process, where rapid learning curves need to be ensured to uphold high efficiency.

Robots' cost digression and increased capabilities

Finally, the cost digression and increased capabilities of robots allow for the cost-efficient deployment of robotics to new areas in the manufacturing process.

In light of these trends, three key Industry 4.0 value drivers promise value at scale in the automotive industry:

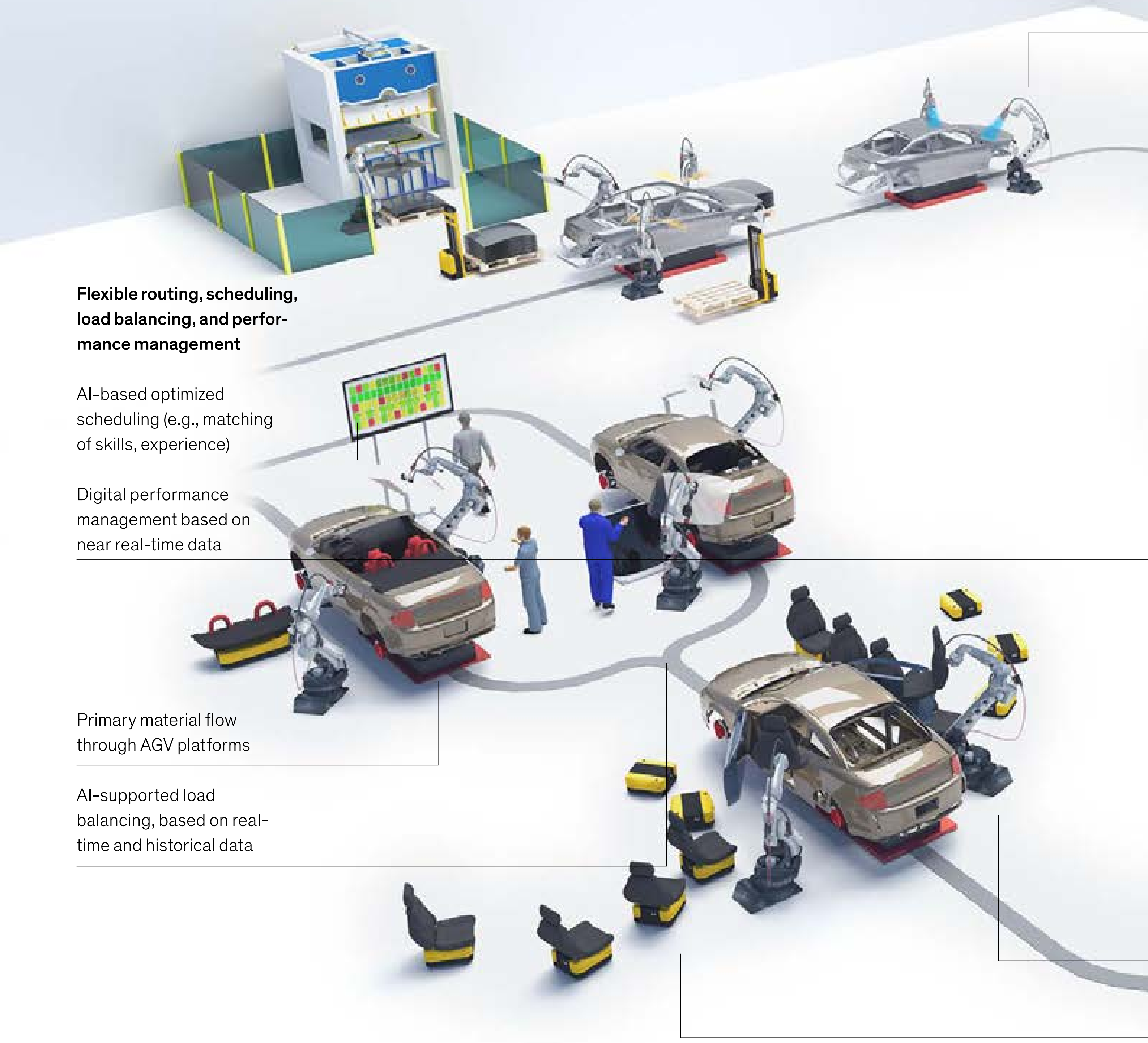
— Industry-4.0-enabled flexible routing, scheduling, load balancing, and performance management based on an integrated manufacturing IT infrastructure and advanced analytics can significantly improve productivity in final and pre-assembly.

— Closed control loops through sensor-based, in-line quality inspection ensure minimum rework through early recognition of process deviations. Especially when new processes and short learning curves are required to respond to shifts in the value chain and process landscape (e.g., induced by increased usage of lightweight materials) closed control loops can capture value at scale.

— An extension of automation to the final assembly, e.g., through AI-powered perception systems or co-bots that enable fenceless robotics, enable significant reductions in labor costs based on the trend toward lower-cost robots with increased capabilities.

The resulting factory of the future target picture on page 26 shows how these key value drivers break down into tangible, value-driven use cases that closely interact with each other in the automotive factory of the future. In the following, we will detail the key value drivers and provide successful implementation examples.

Automotive factory of the future target picture



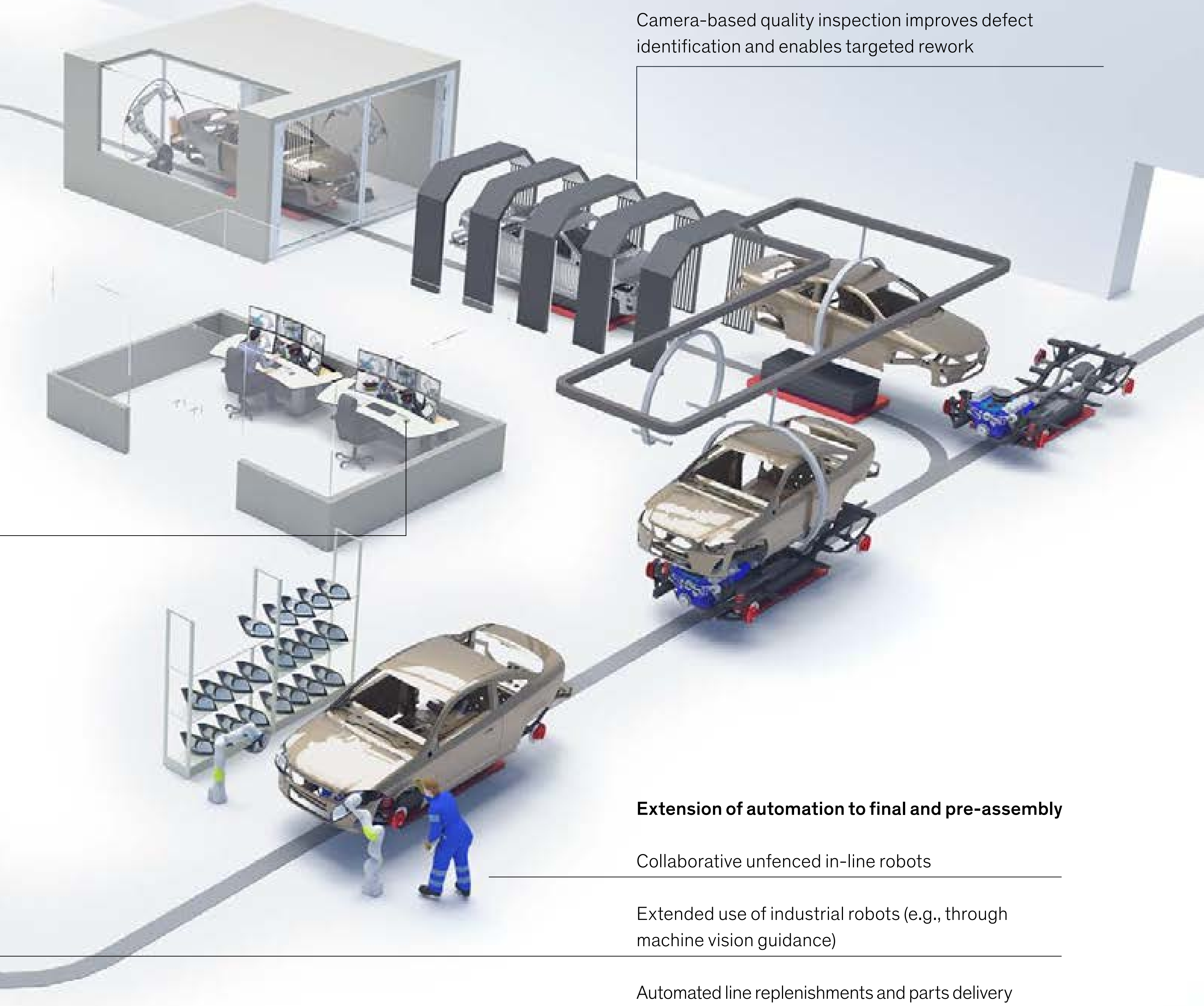
Flexible routing, scheduling, load balancing, and performance management

AI-based optimized scheduling (e.g., matching of skills, experience)

Digital performance management based on near real-time data

Primary material flow through AGV platforms

AI-supported load balancing, based on real-time and historical data



Closed control loops through sensor-based in-line quality inspection

Early detection of process parameter deviation and rapid correction, reducing scrap (e.g., using scanner-based body shop inspection)

Camera-based quality inspection improves defect identification and enables targeted rework

Extension of automation to final and pre-assembly

Collaborative unfenced in-line robots

Extended use of industrial robots (e.g., through machine vision guidance)

Automated line replenishments and parts delivery through AGVs

Additional Industry 4.0 value drivers

Value capture typically only for selected areas: predictive maintenance for production machines and tools, warehouse automation, automated high-capacity battery cell and pack handling

Automotive key value driver – flexible routing, scheduling, and load balancing

Status quo

The scheduling of assembly tasks today is typically based on the rigid direction of the factory's main line and standardized planning times (e.g., based on MTM[10] analysis), where flexibility is granted only to a limited extent and is typically based on some overlapping workstations. However, the high and increasing mix of variants on the line can lead to significant differences in assembly times per vehicle at one workstation, requiring load balancing across assembly stations to avoid flow interruptions and idle times.

AI can help to optimize scheduling and load balancing across lines

In addition, standardized planning times often do not reflect true processing (e.g., assembly) times. Furthermore, individual differences in experience and skill level in the workforce are not properly reflected in the standardized planning times. As a result of current assembly scheduling processes, differences between standardized planning time budgets and true assembly times are often observed, creating significant potential to increase productivity and throughput by reducing waiting times between stations through flexible routing, scheduling, and load balancing.

Scope of action

To capture potential at scale, AI-enabled workforce job scheduling (e.g., matching skills and experience to assembly tasks) can be deployed to optimize workflows. AI can also support load balancing across lines based on real-time process information and historical data. Additionally, the routing of the primary material flow can be made more flexible through, for example, AGV platforms as main load carriers as opposed to a rigid main line. Subsequently, secondary material flows can be rerouted to the new workstations, e.g., based on a fleet of flexible self-guided intralogistics AGVs operating on a centralized control system.

Benefits

AI and automation in routing, scheduling, and load balancing can reduce idle/wait times and lead to increases in labor productivity and throughput in final assembly.

[10] Methods-time measurement

Case example:
Porsche deploys flexible AGV-based assembly line to optimize its electric vehicle production
Porsche is introducing an AGV-based assembly process for the serial production of its electric model, Taycan. Instead of a mere AGV transport of vehicles between assembly stations, the flexible production line concept is based on a takt sequence with assembly workers moving with the AGV through the manual assembly processes following a flow principle. At the same time, the AGV concept allows for vehicles to leave the main line flow when necessary, e.g., for the installation of special interior features, allowing for balancing.

The AGV-based production line is expected to be realized at 30 to 40 percent lower capex than the traditional main line with the majority of savings coming from reduced weight and related building-cost reduction. In addition, the concept promises higher efficiency in operations and shorter ramp-up time from pre-series to series production, as pre-series production concepts can be moved into the series production factory.

30-40%

lower capex

Automotive key value driver – closed control loops through sensor-based in-line quality inspection

Status quo

Currently, nondestructive quality control during the production process at the factory level happens mostly through traditional CMM[11]-based metrology solutions. It is also most often conducted out of line, i.e., by pulling the product out of the production line for inspection in a specially designated area/machine (e.g., climatized metrology room), interrupting production flow. Quality control also typically involves a sampling of work pieces for testing – reserving the 100 percent testing approach for highly critical parts or instable processes.

Based on these sample inspections, process parameters are corrected mostly based on statistical process control procedures, which implies a time delay between detection of processes moving out of "in-spec" parameter range and correction. This typically leads to very narrow definitions of "in-spec" parameters created to detect faults as early as possible. This increases demands for acceptable machine accuracy and process stability. In the case of a detection of a violation of the specification thresholds, it can also mean an often lengthy tracking of parts through the subsequent production steps, where further value has already been added to the scrap parts.

Sensor-based in-line quality inspection facilitates rapid feedback loops for process parameter correction

Scope of action

Sensor-based quality control enables the generation, processing, and interpretation of machine and sensor data for in-line quality inspection and assurance without interrupting production flow. The scope of this value driver includes the use of cameras and scanners for the visual inspection of work pieces (e.g., camera and laser-based body shop inspection, camera-based paint quality inspection). Sensor-based inspection also increases the control rate up to 100 percent, enabling detection of defects earlier in the process. Furthermore, this early detection reduces the value add on parts with defects, minimizing scrap and rework. In addition, the sensor data can be used to guide rework efforts and thus increase rework efficiency in case of damages in paint coatings, for example.

Sensor-based in-line quality inspection facilitates rapid feedback loops for process parameter correction. It does not reactively reduce costs associated with defective parts. Advanced-analytics-supported process simulations, combined with quality inspection data and related sensor information is augmented with specific process domain knowledge to derive optimized process parameters. Starting with reactive suggestions for parameter changes, these process parameter corrections can become automated with direct feedback into production line machinery, thus creating a closed quality loop. In this proactive parameter feedback, there is significant additional value capture through Industry 4.0.

Benefits

Sensor-based quality control limits waste by minimizing the refining of late or defective parts by detecting defects early on and enabling rework to happen even sooner. In addition, closed quality control loops also reduce throughput time by eliminating production flow interruptions.

[11] Coordinate measurement machine

Case example:
Ford automates quality control through camera-based in-line quality inspection

Ford Motor Company uses JAI machine vision cameras for in-line quality control of the painting process to improve defect detection. Ford installed JAI's automated vision systems to identify dirt particles in paint jobs as a replacement for their manual car inspections, which only identified about 50 percent of defects.

JAI's machine vision system consists of 16 high-resolution cameras, detecting dirt particles that are smaller than a grain of salt. The cameras take more than 1,000 images of each painted vehicle surface to create a 3D model of the car bodies in order to identify defects. After introducing this completely automated vision-based inspection system, Ford saw a decrease in inspection time, due to the high rate of 15 frames per second, and a 90 percent improvement in defect detection compared to human inspection.

90%

improvement in defect detection

Automotive key value driver – extension of automation to final and pre-assembly

Status quo

Today, final and pre-assembly is still dominated by manual processes. Labor cost and labor efficiency are therefore the biggest cost drivers in automotive assembly processes. Long and extensive training is required to prevent assembly mistakes and ensure high levels of quality in the high-variant mix on the line, which would lead to expensive rework and further drive cost.

Collaborative robotic systems can safely work side by side with assembly workers

Scope of action

Driven by the decreasing prices and increasing capabilities of robotic systems, the extension of automation to final and pre-assembly comprises two angles. First, the use of industrial robots operating in fenced/defined environments for repetitive tasks can be extended to meet the demands of a high-variant assembly environment. Through machine vision guidance, for example, industrial robots can be made even more flexible, reducing the need to make significant, variant-driven setup investments.

Second, advancements in sensors and virtual safety fencing allow for unfenced in-line robotic applications. Collaborative robotic systems can safely work side by side with assembly workers. Typical applications include areas of module preparation, low-speed/low-precision assembly of parts, or in-line quality inspection tasks at the assembly line (e.g., in-line gap scanning). AGVs also play a role in the extension of automation to final and pre-assembly, replenishing the line and delivering parts.

Benefits

Extending automation to final and pre-assembly ultimately reduces labor costs by enabling lights-out areas in this phase of production.

Case example:
Bosch increases end-of-line parts inspection efficiency through flexible and collaborative robotization by Rexroth

Bosch uses collaborative APAS robots for automated end-of-line inspection on the manufacturing line for, e.g., automotive injection system components. By combining a collaborative APAS robotic arm with a sensor-based quality inspection module, Rexroth has created an efficient end-of-line inspection workstation reaching an OEE of over 90 percent. The solution is also highly space efficient and flexible due to its fenceless setup. In addition, the cell allows for short interruptions of the workflow by automatically and safely stopping the robots through a capacitive sensor skin when workers enter the cell area.

This flexible automation solution was amortized in less than 20 months and represents a significant cost savings over the previous manual inspection setup.

<20 month

amortization

Three additional Industry 4.0 value drivers for automotive

In addition to the three key Industry 4.0 value drivers described above, we see three additional Industry 4.0 value drivers that can create value in selected areas.

Predictive maintenance for production machines and tools can be a lever for capturing Industry 4.0 value in areas where asset productivity and OEE are key and maintenance costs are significant, e.g., automotive press shop. Through the prediction of potential downtime events based on machine/process and quality parameters, process interruptions and maintenance costs can be reduced. However, the criticality of downtimes needs to be carefully weighed against the potential cost savings, as condition-based and preventive maintenance might prove to be better options when considering the manufacturing process holistically.

Criticality of downtimes needs to be carefully weighed against the potential cost savings

Highly automated warehouses in intralogistics can help to capture additional Industry 4.0 value. Warehousing logistics with highly automated material and information flow from inbound logistics, storing, sorting, and retrieving can help to increase parts availability, labor productivity, and supply chain efficiency.

Automation of high-capacity battery cell and pack handling and assembly, with the increasing electrification of the automotive powertrain, can become a value driver in the automotive manufacturing landscape. Depending on the battery cell type and supplier configuration, the introduction of automation systems handling high-capacity battery cells while ensuring positioning accuracy, high yield, and safety can generate significant value in EV powertrain assembly plants. Secure automation is still challenging, especially when the battery architecture relies on pouch cells.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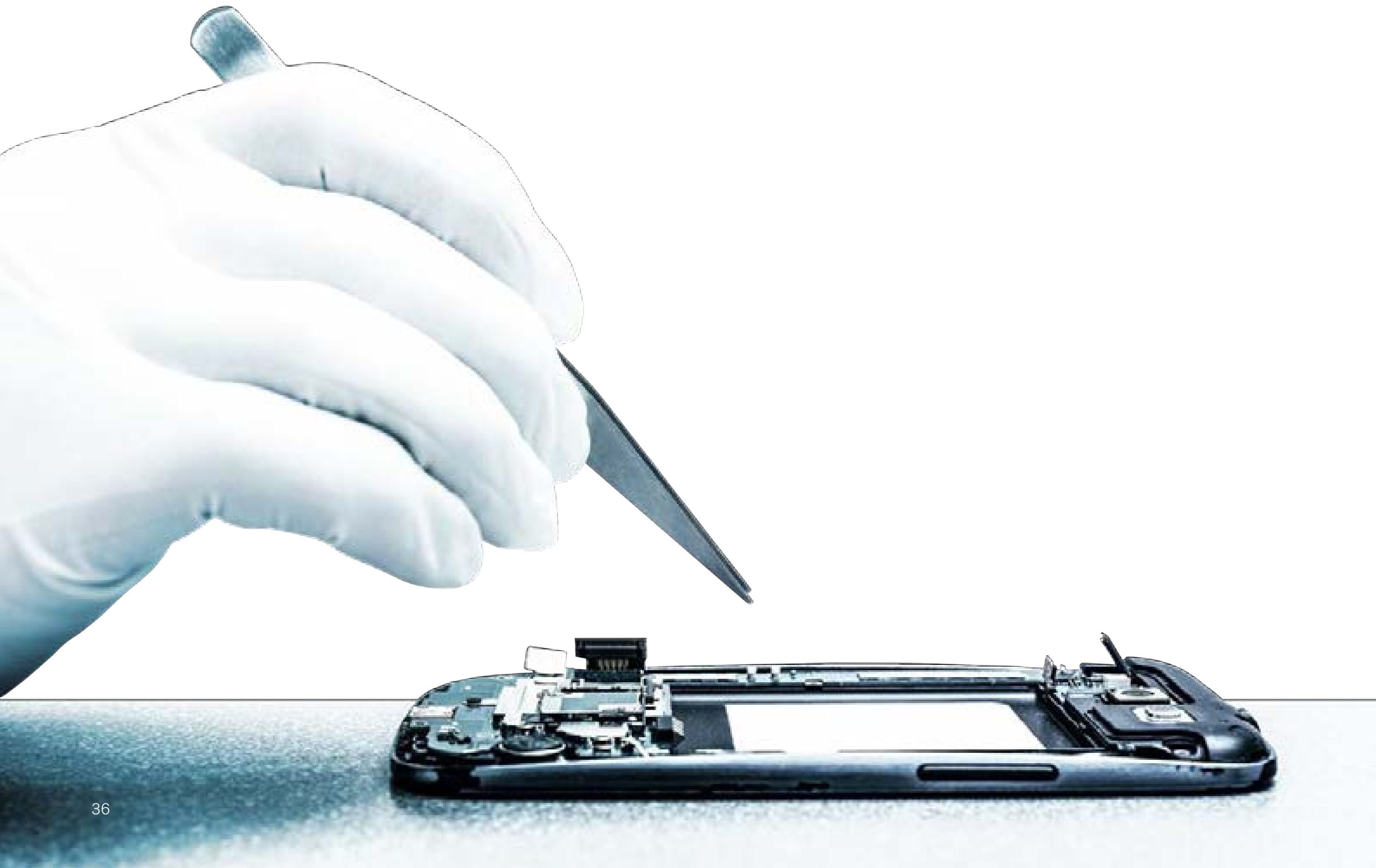
I.III Consumer electronics

Key value drivers and target picture in a "high-volume production" industry

In the last two decades, most consumer electronics OEMs have focused on customer-facing activities, such as brand shaping and product management, as well as marketing and sales. At the same time, they have sought to outsource major parts of their production network to contract manufacturing (CM) companies. The advantage for OEMs to leverage such partners lies in the lower cost base enabled through economies of scale on the CM side, as well as in variabilization of the fixed costs that their own manufacturing capacities would imply. Some CM companies also forayed into product design and R&D, broadening their value creation share and becoming the one-stop shop for the OEM, allowing them stronger differentiation versus competitors. Despite such steps, CM companies face tremendous competitive pressure and continuously strive for operational excellence and higher degrees of automation to further drive down their cost base and increase margins. Given this overall industry situation, we see four major trends shaping electronics manufacturing operations in the coming years that will further increase the potential of Industry 4.0 key value drivers to gain competitive advantage.



Consumer electronics industry trends defining key value drivers

Shorter product technology life cycles
Consumers expect more rapid product innovation, which leads to shorter product technology life cycles. For example, the technology life cycle of television screen technologies decreased from about 30 years for colored cathode ray tube displays to roughly 20 years for LCD panel technology, to about 10 years or less for the latest LED, OLED, and curved screen technology. Each new technology required new manufacturing and assembly equipment and new processes, while the shorter life cycles decreased learning and amortization times.

Higher demand for product variants, increasing competition
The growing demand for product variants and increasing competition often force CMs to manufacture multiple products on a single line in order to avoid the capex associated with new infrastructure.

New workforce characteristics
The workforce is seeing high employee turnover rates (e.g., frequently up to 200 to 300 percent turnover or more in blue-collar positions) rising wages, and an aging population in the core CM manufacturing locations, especially in China. These trends, along with a generally low willingness of the younger end of the workforce distribution to work in repetitive manufacturing tasks, make automation business cases more attractive than ever before.[12]

Shift toward a circular economy
Growing resource scarcity, e.g., precious metals, as well as the growing green consciousness of consumers drive a shift toward a circular economy. The shorter technology life cycles mentioned above further fuel this waste-minimizing trend. Recent government regulations, e.g., the Dodd-Frank Act in the US, have laid down a minerals legislation for 3TG[13] metals requiring a strict chain-of-custody tracking, forcing consumer electronics manufacturers to act.

In the face of these trends, three key Industry 4.0 value drivers will help to capture value in consumer electronics manufacturing:

— Conquering the remaining domains of manual labor through automation – especially in final and pre-assembly lines, testing, and packaging – will counteract the pressure from increasing wages and the decreasing availability of skilled labor. This will also further reduce waste in the face of an increasing product mix and enable closed control loops.

— Closed control loops through sensor-based, in-line quality inspection reduce waste and increase yield through early process deviation detection, root cause analysis, and automatic correction. This helps to accelerate learning curves and accommodate more frequent product changeovers, and contributes to an overall more resource-efficient and thus both more economical and greener manufacturing through lower waste. Furthermore, closed quality control loops and the increasing degree of automation gain value, as human error is avoided and the fully automatic correction of any deviations becomes possible.

— Implementing traceability of components and products throughout the supply chain enables transparency, from basic material processing and refinement to the on-the-shelf product to recycling. Traceability has facilitated warranty claims and recalls and allows OEMs/CMs to zero in on the suppliers, component batch, and the specific process step that has led to a particular defect. This traceability is also a key enabler of a circular economy and supports the anticounterfeit measures of OEMs. In addition, traceability helps to control the production process by establishing the link between any potential product flaws and the precise set of parameters used in the manufacturing process.

Starting on page 38, the resulting factory of the future target picture breaks these key value drivers down into tangible, value-driven use cases that closely interact with each other in the consumer electronics factory of the future. In the following, we will detail the key value drivers and provide successful implementation examples.

[12] The share of population aged 65 and older will increase from 9 to 17 percent by 2030. "Jobs lost, jobs gained: Workforce transitions in a time of automation," MGI, 2017
[13] Tin, tantalum, tungsten, gold

Consumer electronics factory of the future target picture

Conquering remaining domains of manual labor through automation

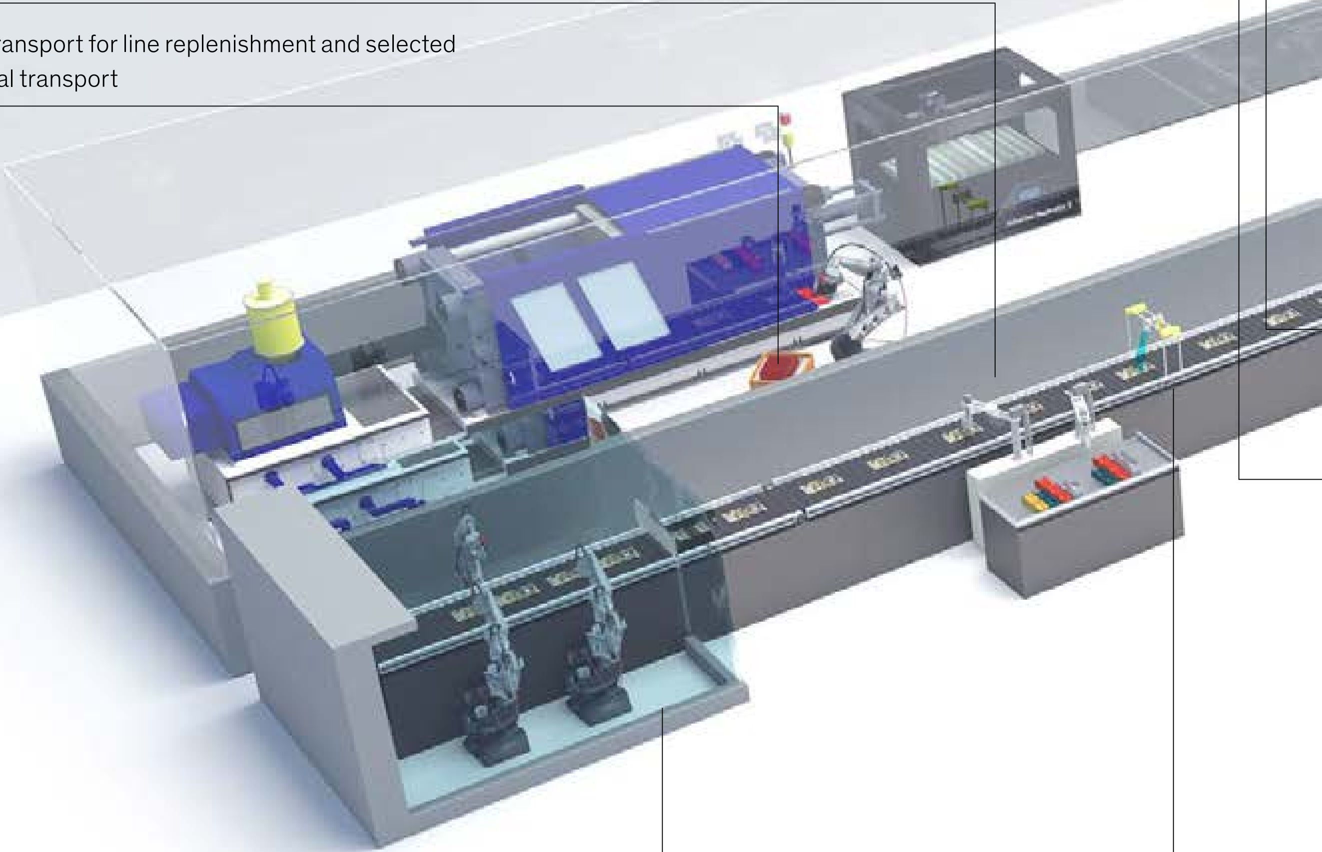
Automated component treatment and preparation (e.g., case polishing)

Robotic discrete assembly, micro-screw tightening, and adhesive joining

Robot-supported product dismantling and recycling

Robot-supported component assembly on circuit boards

AGV material transport for line replenishment and selected primary material transport



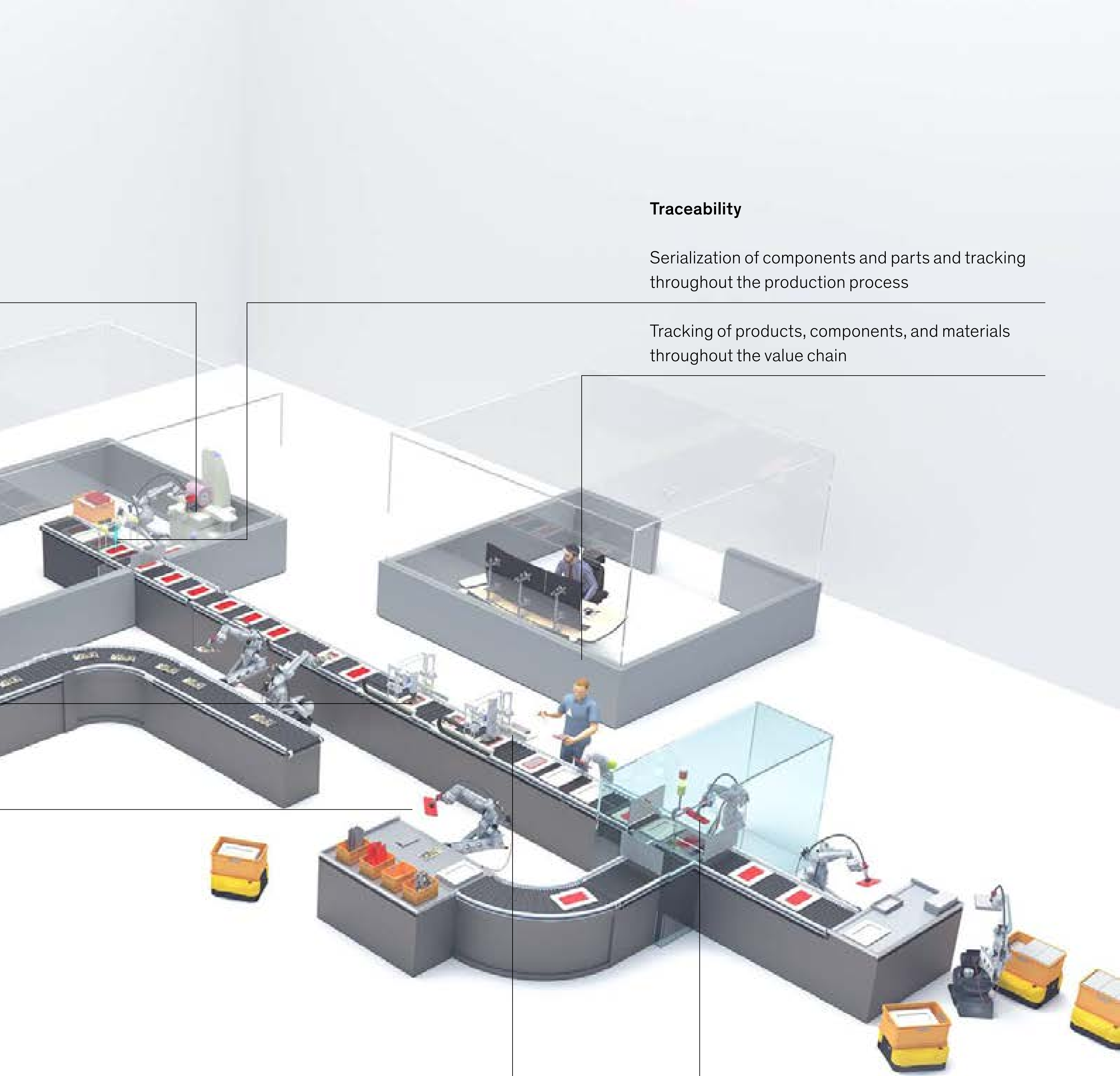
Closed quality loops through sensor-based in-line quality inspection

Automated process parameter adjustment and optimization based on quality data

Enhanced in-line quality inspection for early defect detection (e.g., 3D scanning of PCB assemblies)

Quality assurance of discrete assembly (e.g., with vision-equipped robots capable of inspecting and correcting misaligned parts)

Fully automated end-of-line functional hardware and software testing and quality assurance



Traceability

Serialization of components and parts and tracking throughout the production process

Tracking of products, components, and materials throughout the value chain

Additional Industry 4.0 value drivers

Value capture typically only for selected areas: digital performance management

Consumer electronics key value driver – conquering remaining domains of manual labor through automation

Status quo

While the overall process of consumer electronics manufacturing is already automated in many areas – especially where tasks are highly repetitive (e.g., PCB assembly in SMT lines) or working conditions are dangerous (e.g., polishing) – there are some process steps where manual labor still plays an important role (e.g., harness and ribbon connector assembly and assembly of highly flexible parts, such as thin films). Traditionally, relying on a comparatively untrained labor force, the manufacturing and assembly lines have been characterized by the division of labor in very small increments, allowing for the relatively fast training of new employees. Quality is ensured at the end of the line either with skilled workers or testing technologies.

Full automation is often also perceived as "getting lean for free"

Scope of action

Replacement of manual workstations with automated processing solutions is implemented based on detailed analysis of manual assembly operations and process requirements. Processes such as parts placement, tapping and micro-screwing, as well as quality control are automated mostly by deploying traditional industrial robots and linear automation solutions. During the selection of the automation solutions, flexibility needs arising from the product mix on the line as well as from anticipated future products are accounted for to increase the life cycle of the automation equipment.

For successful automation, a detailed analysis of the production process flow is necessary, allowing for process streamlining and waste reduction. Together with the highly automated process flow, in-line quality inspection and assurance solutions are typically installed to enable an uninterrupted material flow.

Benefits

Doing so allows for significant throughput and quality improvements, e.g., lines running twice as fast with half the quality issues by eliminating the process instabilities and inefficiencies related to human labor.

Furthermore, full automation is often also perceived as "getting lean for free," as automated processes strictly follow the flow principle and highly standardized manufacturing steps.

Case example:
Global electronics contract manufacturer introduced robotic automation solutions to reduce its labor cost in selected areas by 80 percent
A global electronics contract manufacturing company started its enterprise-wide digital manufacturing transformation journey with a detailed evaluation of its manual operations. It identified robotics technologies that would allow for the automation of manual tasks. These were predominantly found in pick and place, screwing, labeling, and in some wiring, as well as in connector plugin applications. In addition, the automation of quality assurance processes was identified as a main potential. A lead automated line was designed by rethinking processes and developing solutions that enable a high level of flexibility to accommodate multiple future products. As a result of the higher degree of automation, labor cost was reduced by 80 percent. In addition, significantly higher levels of process efficiency and quality were reached.

Labor cost reduction

80%

Consumer electronics key value driver – closed quality loops through sensor-based in-line quality inspection

Status quo

In-line quality control is finding increasing application in consumer electronics manufacturing. In-line capacity sensors are applied to detect the presence of parts on the line, and temperature sensors allow for process control. In addition, vision systems for dimensional checks, surface inspection, OCR/OCV, as well as guidance and location tasks are becoming increasingly common. Vision systems are also becoming increasingly adopted in end-of-line screen quality control (dead pixels, calibration level, etc.) and to verify wire or screw presence in between assembly steps.

Closed quality loops can significantly reduce the number of quality issues and rework

Scope of action

Closed-loop quality control through sensor-based in-line quality inspection and assurance builds on two pillars to capture value at scale. Firstly, by increasing the deployment of sensors and vision systems with advanced-analytics-supported sensor data and image interpretation, the earlier detection of defects is made possible. From identifying and differentiating among multiple labels of assembled parts and detecting false installation to verifying screw positions, the early detection of errors reduces rework and scrap.

Secondly, the in-line sensor data enables advanced-analytics-supported quality improvements by enabling the closing of the quality control loop. As a first step, the identification of key parameters influencing product quality based on sensor data provides insights on the processes, process sequences, or workstations that are critical for overall product quality. Based on this identification of critical processes, parameter correction models can be derived. These models enable automated process parameters, real-time corrections, and in-line sensor data feedback, thus closing the quality control loop. Examples include automated robot calibration in label positioning. Based on the visual inspection of the label position in the assembly line, deviations are detected, and labeling robot motion parameters are automatically adjusted. Going beyond the factory floor, the data gathered through closed-loop quality control can be fed back to engineering departments to improve product design for manufacturability in later design revisions.

Benefits

Closed quality loops can significantly reduce the number of quality issues and also reduce the need for labor-intensive and inefficient rework areas. Closed quality loops can also enable shorter product line yield ramp-up times and faster process learning curves. Overall, the implementation of closed quality loops through sensor-based in-line inspections increases OEE and enables self-improving processes.

Case example:
Samsung uses cutting-edge 3D vision scanning to tackle growing demand and strict quality standards for LCD panels

Samsung introduced 3D scan-based automated inspection to replace the manual process of inspecting LCD panel flatness, which proved to be a bottleneck in the manufacturing process. Automated in-line inspection is based on color filter inspection systems operating at the same speed as the production line. The systems identify internal panel and surface defects. Defects are reported in real time to operators, with the precise X-Y coordinates of the issue and information on the type of defect. Changing to a sensor-based in-line inspection increased the speed of the inspection process from minutes to less than one second per screen. Production line output and throughput time were significantly improved, and the bottleneck in the inspection process was removed. Customers benefited from defect-free products as a result of upstream defect identification and resolution.

<1 second

inspection time per screen

Consumer electronics key value driver – traceability

Status quo
Traceability of products and components throughout the entire supply chain is increasingly demanded by OEMs as a procedure CMs have to comply with in order to be an eligible manufacturing contractor. Efficient ways to create supply chain transparency are thus gaining importance. Tracking throughout the supply chain today is, however, mostly based on certain control points with a significant time lag between the registration points.

Benefits
Traceability enables the securing of customer orders and market access through complying with standards and regulation. Based on the data gathered throughout the production process and supply chain, countermeasures to resolve quality issues on the customer end can be taken more quickly and with a clearer scope (e.g., whether single products, several, or whole product lines are affected).

Industry 4.0 enables real-time tracking from supplier, to the plant, to the store

Scope of action
Industry 4.0 improves upon current efforts to trace products throughout the supply chain by enabling real-time tracking from the supplier to the plant to the store. Specifically, the combination of IIoT connectivity with new data verification technologies (e.g., blockchain) enables increased traceability along the supply chain. In the value chain steps up- and downstream of manufacturing, IIoT clouds enable easier tracking and verification of component origins, higher quality, and better identification of counterfeit products.

Case example:
Seagate plans to utilize IBM Blockchain and electronic fingerprinting to track supply chain for hard drives

In order to fight counterfeit hard drives, Seagate and IBM are working together to utilize blockchain to track the movement of hard drives from the point of manufacture to the point of sale, and vice versa if necessary. For this purpose, the hard drive's authentication data will be updated on the IBM Blockchain Platform based on Seagate Secure Electronic ID, which will serve as a unique identifier. Each identifier works as an electronic fingerprint and verifies the identity of a hard drive. As a result of its constant updates, blockchain provides an immutable record of events along the hard drive's life cycle and enables vendors, service providers, and end users to confirm the source at any point in time. This promises to be an effective countermeasure against counterfeit electronics, amounting to an estimated USD 1.7 trillion in value per year globally.

Effective measures against counterfeit electronics

Additional Industry 4.0 value driver for consumer electronics

Digital performance management enables significant efficiency gains, especially in areas where manual labor remains dominant. Providing supervisors with near real-time feedback on performance variations within the line and early warning in case of process instabilities enable quick countermeasures and continuous improvements. Individual operator performance tracking, life cycle time adherence follow-ups per station, and performance-based work allocation in the repair shops can thus generate significant improvements on the operator level. In addition, information can be passed upward, creating transparency of manufacturing performance in all manufacturing locations and allowing for easier operations management, reporting, and best-practice transfer.

Case example:
Interactive work instructions at Jabil Circuit

Jabil Circuit uses tablet-based interactive work instructions from Tulip to guide their electronics assembly and run process analytics at the same time. Customized apps provide the operators with visual instructions about the assembly steps and enable them to track and report quality issues in real time. The former paper-based work instructions and audit procedures have been fully replaced. The data gathered from the shop floor are continuously analyzed with Tulip's analytics engine. Within four weeks of implementing the digital work instructions, Jabil Circuit gained more than a 10 percent increase in production yield and a 60 percent reduction of manual-assembly-related quality issues.

+10%

production yield

II. How to scale – focusing on value, mobilizing the organization, and innovating the infrastructure

Along with developing a perspective on where to focus, the second element to address in order to capture the full Industry 4.0 potential is how to scale. Our research – supported by our client experience and industry observations – reveals that focusing on three key principles enables large-scale value capture.

II.I Focus on key value drivers – value backward, not technology forward

Focusing on what actually creates value instead of on how the most cutting-edge technologies might be implemented ensures value-backed decision making. As we laid out in the first section of this report (see page 12), a clear prioritization of industry-specific key value drivers allows organizations to demonstrate impact from Industry 4.0 with short payback periods. It also enables the organization to generate value with the resources already at hand. The industry target pictures for machinery (see page 16), automotive (see page 26), and consumer electronics (see page 38) provide an overview of the most relevant value drivers within each industry archetype. The overall vision for Industry 4.0 should be formulated according to these drivers. Selected lighthouse projects can drive the visibility and strengthen the support for the Industry 4.0 transformation throughout the organization.

II.II Mobilize the organization – it is all about people; tools alone will not solve the problem

Industry 4.0 requires an organizational transformation. If the focus is only on the introduction of new digital tools without the full enablement of the organization, the implementation of Industry 4.0 will, at best, capture application-specific value at the fringes. In contrast, leveraging the organization's domain and process expertise as well as sustainably building up new skillsets and capabilities supports a successful transformation with lasting impact for the company overall.

McKinsey research insight

"Organizations that invest in developing leaders through the transformation are ~2.4 times more likely to succeed"[14]

Mobilizing the organization

An organization-wide mandate coming from the top is fundamental to a successful Industry 4.0 transformation. Companies leading in generating financial impact through Industry 4.0 and IIoT are also more committed to (and successful at) pursuing and securing senior executive support for their Industry 4.0 efforts than those lagging behind (see page 49). Specifically, the transformation should be backed by the commitment of the P&L owners to ensure adequate pace and widespread adoption. To generate and maintain momentum, interim results and success stories should be shared regularly throughout the organization. Demonstration of the organization's commitment to the Industry 4.0 transformation might include digital immersion sessions and "go-and-see visits" by the top management team. From a staffing perspective, a clear, executive-level transformation leader should be appointed by the executive team to drive the transformation.

Integrated decision making and coordination across all relevant functions and value chain steps complement the vertical organizational strategy. Across the organization, cross-functional teams will break down the barriers between functions and, thus, foster innovation. A comparison of leaders and laggards shows that leaders enjoy stronger internal organizational alignment (see page 49).

[14] Comparison of percentage of transformations that were very or extremely successful, McKinsey Transformational Change Survey

Key insights from Industry 4.0 implementations

3 key principles for capturing value at scale

What is needed to successfully leave the pilot purgatory

Focus on value drivers

Think value-backward, not technology-forward, focusing on industry-specific key value drivers

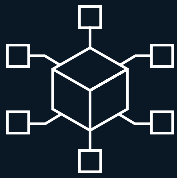
Develop a compelling vision and inspire the organization through lighthouse pilots

Mobilize the organization

Drive the transformation from the top with clear business ownership

Lock in bottom-line benefits quickly to prove the value early

Build capabilities and cultivate a highly agile culture



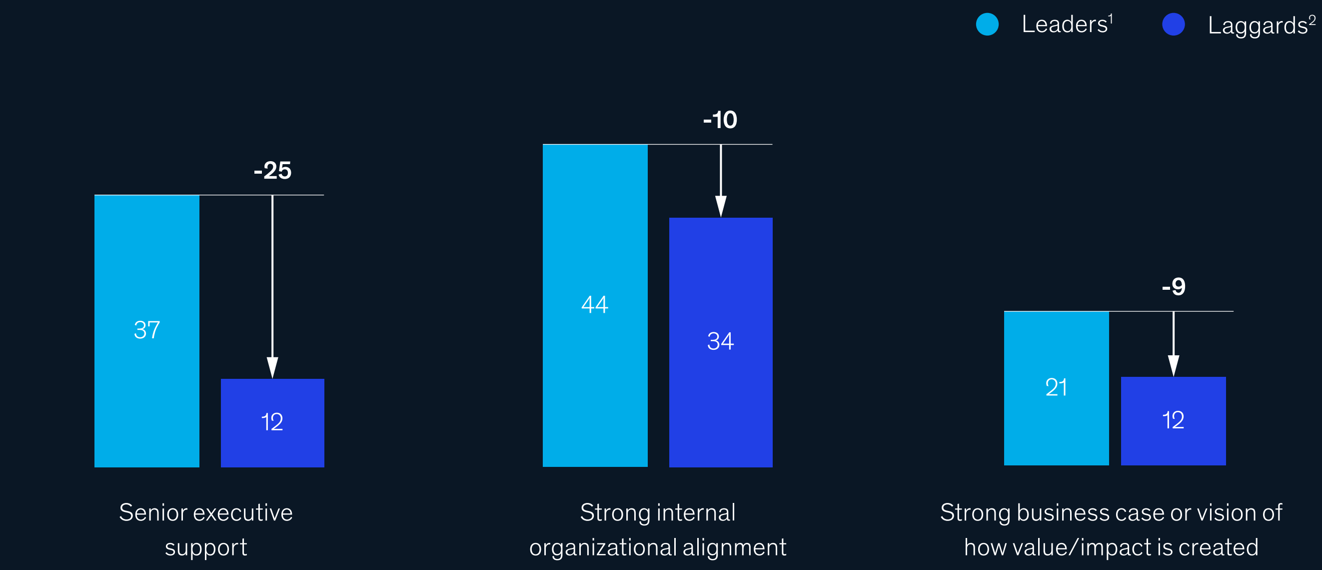
Innovate the infrastructure

Define an integrated target technology stack based on a thorough analysis of the status quo

Choose transition pathway and enable locally before scaling globally

Learning from how Industry 4.0 leaders mobilize the organization

Key success factors for successful Industry 4.0/IoT programs
Percent citing factor no. 1 or no. 2



1 >15 % combined cost savings and revenue gain
2 <5% combined cost savings and revenue gain

Addressing the capability gap

Getting the right skills and capabilities in place is another success factor for Industry 4.0 transformations. Organizations will need to identify skill gaps and complement their existing company domain knowledge in order to close these gaps in the areas of, for example, advanced analytics, artificial intelligence, and IoT stack architecture.

Necessary skills and capabilities can be built through a combination of internal training, the acquisition of new talent, and collaborations with tech-solutions providers and research and academic institutions. However, capability building alone is not enough to capture and sustain the full value of Industry 4.0; it is imperative that these new capabilities become institutionalized and do not exist as separate or add-on skills. Companies will need to cultivate a culture that sustains new capabilities by integrating them with current capabilities and understanding them as essential to value creation.

II.III Innovate the infrastructure – moving towards an integrated technology stack, optimizing locally before scaling globally

Implementing Industry 4.0 requires a transformation of both the IT infrastructure and automation technology stack. Based on the research from McKinsey's 2018 white paper, "Leveraging industrial software stack advancement for digital transformation," the following section lays out how to succeed in this transformation. It is essential to begin by establishing a clear baseline of where the company stands today. Next, the organization will develop a clear picture of the target architecture and then map out the transition path best suited for the particular industry and company context. Throughout the process, an organization should operate under the principle that an initial focus on local enablement is key to ensuring early value capture.

Create transparency on the status quo

The baseline found in many companies today can be described as follows: the enterprise software layer is not connected consistently to the factory, line, or machine level. Often, data is not collected at all or is fragmented between organizational silos. Manual translation between the enterprise and operations layers (often via a spreadsheet software) leads to limited transparency and is prone to human errors. Furthermore, either no MES or multiple ones for different value chain steps are in place with little to no interconnection; integration with SCM and other enterprise systems is mostly missing. Last but not least, there is a low level of interconnectedness between process steps, few sensors/analytics are built in, and most machines within lines are not interconnected.
Of course, some industries and companies have already made progress on their Industry 4.0 transformations and solved some of the challenges outlined above, e.g., through building up dedicated analytics capabilities and connecting key components of their manufacturing ecosystem. Despite the progress made by some, very few have achieved a fully integrated industrial automation stack.

Define the fully integrated industrial automation stack target picture

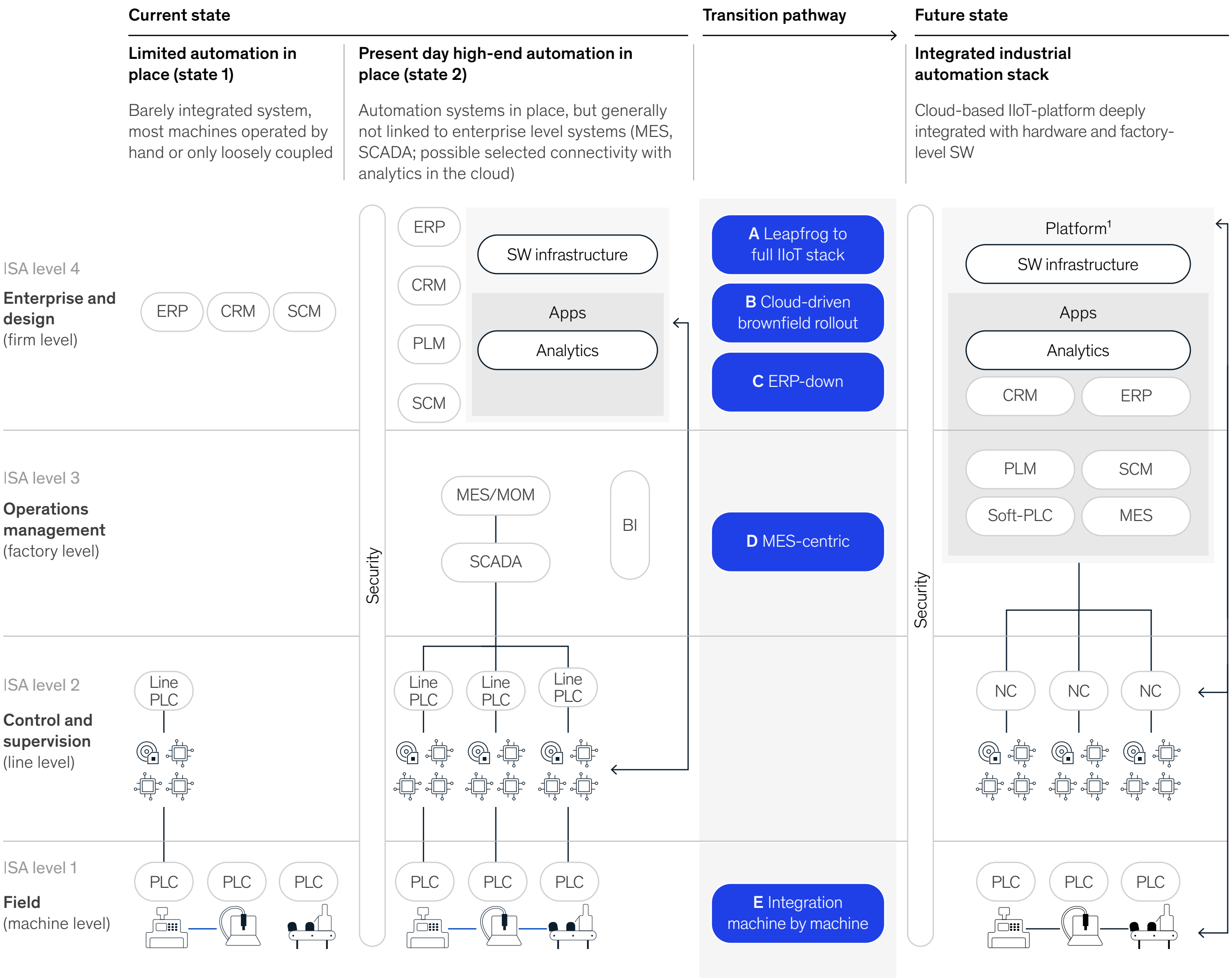
In the fully integrated industrial automation stack, which can serve as a target picture for an Industry 4.0 transformation, the integration of operational shop floor data with back-end systems (e.g., ERP, EAM) creates full transparency across all value chain steps and levels of the organization. A focus on analytics and applications strengthens the organization's ability to process real-time information, including edge analytics to improve operations (e.g., advanced process control, predictive maintenance). The semantic integration between shop floor devices and control systems, potentially bypassing the MES layer, and secure data transmission channels across different network connections technologically enable the convergence of shop floor and top floor.

Choose the right transition pathway

There are multiple paths along which an organization can travel on its journey from status quo to the target state (see Exhibit 2). The optimal path will depend on both the starting situation and the industry vertical in which the company operates. In general, "wrap and extend" instead of "rip and replace" is a guiding credo for most Industry 4.0 infrastructure innovation.

Exhibit 2

Pathways to an integrated industrial automation stack for Industry 4.0



Description	Archetype and vertical example	Key challenges
A Leapfrog to full IIoT stack		
Leapfrog from current state 1 to full platform, mostly in greenfield situations with a clear vision for the IoT	**Small-lot manufacturing** (e.g., machinery) Smaller/less complex factory operations with significant benefits from real-time factory control and analytics allow for leapfrog	Lack of experience may result in long ramp-up times Integration challenges
B Cloud-driven brownfield rollout		
Upgrade from current state 2 in brownfield situations to a fully integrated plant	**High-volume production** (e.g., consumer electronics) High affinity towards digitalization, with significant room for improvements in automation	Integration of legacy systems and step change move
C ERP-down		
Leverage existing ERP software and use it as integration backbone, moving down to MES	**High-volume production** (e.g., consumer electronics) New manufacturing lines or new factories of large EMS players	Requires multiple instances across different plants Master data management (MDM) often separate from EPR
D MES-centric		
Build upon existing, well-established MES software and integrate both up- and downwards	**Mass-customized production** (e.g., automotive) OEMs that deploy mature MES to coordinate complex factory operations	Difficulty scaling across plants Requires multiple instances across different plants
E Integration machine by machine		
Upgrade existing machines with edge analytics and/or develop integration on PLC/NC level to run overarching data	**Small-lot manufacturing** (e.g., machinery) Factory operations with long machine life cycles and interrelated processing steps with high quality demands (in need for error tracking capabilities)	Full move to IIoT architecture very challenging, as no common foundation to integration Difficult to connect to competitor's PLCs

1 Platform can be hosted on premise, as company-internal service or by third party

Source: "Leveraging industrial software stack advancement for digital transformation," McKinsey white paper, 2018.

Enable locally before scaling globally
Transparency on the infrastructure starting position, the automation stack target picture, and the transition path to reach this target picture are important aspects to ensuring the success of an Industry 4.0 transformation, as they will enable scalability of the impact created. However, while scalability is important, an overemphasis on infrastructure in the beginning of an Industry 4.0 transformation can slow down momentum and derail the focus from pragmatically capturing value in the operations. For example, on-premise solutions often already enable the value capture of key use cases, and if designed correctly, can later be integrated into the overall target picture architecture. Based on our Industry 4.0 use case data, only about 30 percent of the use cases are highly dependent on infrastructure that is connected across manufacturing sites, while an additional 15 percent are expected to show significantly improved benefits.[15] Thus, especially in the early days of the Industry 4.0 transformation, focusing on global IT infrastructure first is often associated with high-risk, high-effort, and long-term investments.

Focusing on local value capture can help make an early case for infrastructure innovation

An initial focus on local value capture can help make an early case for infrastructure innovation and ensure value-backed decision making. After an organization successfully locks in the value from local deployment, it can implement the "wrap-and-extend" principle outlined above to expand the infrastructure and begin to capture global value.

Exhibit 3

Phases and next steps on the Industry 4.0 journey

	Industry 4.0 phase		
	I. New to Industry 4.0	II. Piloting Industry 4.0	III. Scaling Industry 4.0
Objective to reach next phase	Develop perspective on key value drivers Understand your Industry 4.0 ecosystem Set up top-management-supported Industry 4.0 team and start pilots	Identify key value drivers for deployment at scale Embark on local transformation journey Create transparency on current infrastructure and sketch integrated target automation stack	Begin rollout of Industry 4.0 value drivers across manufacturing sites Mobilize the larger organization in rolling out the transformation Choose transition pathway and scale technology stack where value adding
Exemplary next steps on the journey	Visit industry roundtables Learn about best practices Visit potential ecosystem partners Understand culture and talent gaps	Build Industry 4.0 partner ecosystem Focus activities Learn through pilots and stop pilots without value add	Scale infrastructure, skills, and capabilities, leveraging the Industry 4.0 ecosystem Transform culture

[15] Comprehensive list of use cases can be found in "The Next Economic Growth Engine Scaling Fourth Industrial Revolution Technologies in Production," WEF/McKinsey white paper, 2018

Outlook – next steps for capturing value at scale

The next steps on the Industry 4.0 transformation journey depend on where your organization currently stands in the three phases towards global Industry 4.0 value capture (Exhibit 3). When new to Industry 4.0, identifying key value drivers for pilots is the top priority. For many organizations, a perspective on how to capture Industry 4.0 value has not yet been developed, and only isolated first initiatives exist in some areas. If this is the case, identify key value drivers based on your factory archetype and industry trends as the first step on your Industry 4.0 transformation. Developing this solid perspective can help facilitate rollout and keep your organization from stagnating in pilot purgatory. At the same time, setting up a top-management-supported Industry 4.0 team to start the pilots is key.

If you are currently in the phase of piloting Industry 4.0 solutions, focusing on key value drivers and starting the local transformation is essential. With the first Industry 4.0 pilots up and running, you have the benefit of being able to use early results to both demonstrate value potential and determine the infrastructure required to capture value on a larger scale. As a next step, identifying the key value drivers for deployment at scale and the development of a roadmap toward scaling should be at the top of the agenda. Together with the roadmap, embarking on the local transformation process is necessary as a way to gain early traction. Specifically, enabling the organization and gaining an understanding of what a comprehensive technology stack for infrastructure innovation should look like lays the foundation for value capture on a larger scale.

For organizations that have achieved Industry 4.0 value at scale, rolling out key value drivers in a full-scale organizational transformation across the manufacturing footprint and the supply chain is key. After key Industry 4.0 value drivers have been identified for selected manufacturing sites and value is captured at scale locally based on a locally enabled organization and infrastructure, global scaling is within reach. As a next step, identify the relevant Industry 4.0 use cases that would most benefit from a connected solution across the manufacturing footprint. This will help to define the scope of a larger rollout. Mobilizing the organization on a larger scale across the manufacturing footprint in a larger transformation is then needed to ensure sufficient enablement. Scaling the initial technology stack targeted to solutions where value can be captured across plants also innovates the infrastructure in a way that enables further rollout. However, the ongoing rollout toward global scale does not end here. The value captured will only be sustainable when the organizational momentum and implemented manufacturing organization is able to attract and retain the talent necessary for further Industry 4.0 deployment. Hence, upholding the organizational culture for digital manufacturing is a task beyond the transformation effort.

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