EIGHT KEY CONSIDERATIONS WHEN IMPLEMENTING
AI IN MANUFACTURING

PLANNING FOR SUCCESS IN YOUR JOURNEY TO IMPLEMENTING AI

What Is Autonomous Manufacturing
Manufacturers are implementing Industry 4.0 concepts to make their processes more intelligent and agile. ... read more

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Industry 4.0 is facilitating a move to software-defined manufacturing (SDM) systems that are much more flexible and agile than today's fixed-function. ... read more

Insights from an Intel Manufacturing Technologist
Is Intel using AI in manufacturing? Has AI impacted your databases? How do you minimize machine downtime? ... read more
With the emergence of regulatory, socio-economic, and pandemic concerns, manufacturers are accelerating their artificial intelligence (AI) and data analytics efforts to meet the need for more autonomous manufacturing lines.

**Autonomous manufacturing**

Why the high hopes for autonomous manufacturing? The key drivers for autonomous production systems are to enable machines to improve their own performance and make insightful decisions that can be acted on by industrial systems, like manufacturing execution systems (MES), material requirements planning (MRP), and enterprise resource planning (ERP).

**Role of AI**

AI enables machine decision-making that can be used for quality control, preventive maintenance, throughput optimization, etc. Those companies willing to invest in AI will continue to lead the manufacturing industry.

**AI and Industry 4.0**

The concept behind Industry 4.0 is largely to attain higher levels of digitalization of industrial environments, enabling greater efficiency, agility, and productivity through real-time, data-driven control of industrial operations. AI is a powerful and essential vehicle for increasing Industry 4.0 productivity and efficiency, and for paving the way to autonomous manufacturing.

“Robots already play a central role in this new era of hyper-agility and autonomous production, and their importance to industrial processes will continue to grow. Our own research points to a positive shift in manufacturers’ perceptions of intelligent factories and automation,” said Christine Boles, Vice President, Internet of Things Group – General Manager, Industrial Solutions Division.”

This document takes you through key considerations when implementing AI with an eye towards autonomous manufacturing. Some of the concepts discussed here are also covered in more detail in two similar Intel documents on edge computing and 5G in industrial environments.

**WHAT IS AUTONOMOUS MANUFACTURING**

Manufacturers are implementing Industry 4.0 concepts to make their processes more intelligent and agile, enabling them to better respond to market uncertainties and customer demand for greater personalization and fulfillment flexibility.

This phase, called the intelligent or smart factory, will be followed by autonomous manufacturing—a phase with higher digital intensity that allows manufacturers to greatly reduce or eliminate human intervention at the operations level. Moreover, production processes will continuously improve through the ability of manufacturing equipment to make decisions and self-optimize.

**Human intervention**

Some participants in an Intel survey of manufacturers stated the future factory, even if run by robots, still needs humans on premises—just in case.

**Higher digital intensity**

Autonomous manufacturing is founded on the control of a holistic view of quality and production data from start to finish. Two essential digital requirements are:

- **A data-model-driven view of production**
  - This view adapts to learnings from AI, machine learning (ML), and deep learning (DL) technologies.

- **Software-defined control systems**
  - Control systems have the flexibility to carry out manufacturing process enhancements determined by AI, ML, and DL technologies.

## Benefits of More Adaptive and Autonomous Manufacturing

1. Continuously optimize production line performance
2. Automatically identify root causes of process issues
3. Swiftly react to production quality variances
4. Quickly respond to production flow changes
5. Rapidly reconfigure and repurpose production lines
6. Increase coordination between production equipment
7. Eliminate error-prone human intervention
8. Decrease the need for manual reprogramming
9. Minimize downtime with equipment self-diagnostics
10. Implement tighter control limits

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### GLOSSARY OF ACRONYMS

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<tr>
<th>Acronym</th>
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<tr>
<td>AI</td>
<td>Artificial intelligence</td>
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<td>COTS</td>
<td>Commercial off-the-shelf</td>
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<td>DL</td>
<td>Deep learning</td>
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<td>ERP</td>
<td>Enterprise resource planning</td>
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<td>FPGA</td>
<td>Field-programmable gate array</td>
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<td>Graphics processing unit</td>
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<td>IA</td>
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<td>IoT</td>
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<td>IIoT</td>
<td>Industrial Internet of Things</td>
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<td>IT</td>
<td>Information technology</td>
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<td>MEC</td>
<td>Multi-access edge computing</td>
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<td>MES</td>
<td>Manufacturing execution systems</td>
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<td>ML</td>
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<td>Material requirements planning</td>
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<td>OT</td>
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<td>ROI</td>
<td>Return on investment</td>
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Software-Defined Manufacturing

Industry 4.0 is facilitating a move to software-defined manufacturing (SDM) systems that are much more flexible and agile than today’s fixed-function, monolithic manufacturing systems. SDM decouples manufacturing software and hardware, so processes and tasks, like “predictive analysis,” can be run on different general-purpose hardware platforms, such as edge computing devices or IoT gateways. SDM systems also enable autonomous manufacturing by providing manufacturers the flexibility to dispatch AI algorithms where and when they are needed.

Microservices

Software processes and tasks can be realized as microservices designed to simultaneously run on a wide variety of platforms, and dispatched and terminated as needed. Typical microservice categories are:

- **Application services**
  Extract, process/transform, and send sensed data to an endpoint or process.

- **Device services**
  Control and interact with manufacturing devices, like sensors and actuators.

- **Core services**
  Provide intermediary communications and a data repository between manufacturing devices and IT systems.

- **Analytics services**
  Perform complex AI-based actuation based on sensor data.

Microservices framework

An example of a framework supporting microservices is EdgeX Foundry®, an open source project under the LF Edge® umbrella within The Linux Foundation® that provides a key ingredient and a forum for participants to collaborate. EdgeX Foundry’s framework has reached more than five million container downloads. Figure 1 shows examples of microservices deployed on an edge computing device.

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2. Develop Industrial Protocol Convergence Strategy

A fundamental reality of Industry 4.0 is it must be tackled from the bottom up, starting with getting OT infrastructure connected and data normalized. This can be a complex endeavor given the operational domain may encompass many different protocols and communications networks.

**Standards body**

IIoT technology was created to help solve manufacturing device connectivity and data convergence issues, reinforced by powerful open standards. One of a wide range of open standards bodies focused on industrial manufacturing is the Open Process Automation Forum (OPAF), which launched in November 2016.

The forum has a diverse membership, consisting of end users, control system manufacturers, control system integrators and suppliers, and academics, as well as other standards organizations. A key objective is to establish a process control architecture that is standards-based, open, secure, and portable.

**Machine protocol standards**

OPAF is part of The Open Group and has developed a standards-based, open, secure, and interoperable process control architecture developed through the collaboration of global leaders in process industries, systems integrators, suppliers, integrated DCS vendors, academia, and other standards organizations.

3. Make Databases Ready for AI

Imaging and other AI-based applications tend to generate huge amounts of data that create large implications for databases. It is important to structure databases to store different data types, like images from dynamics pick and place machines and time-series data for stepper motors. At some point, this data is ingested, stored, and fused, and it may be necessary to perform these applications in near real time.

**Database location tradeoffs**

Where AI algorithms run, at the edge or in the cloud, has a large impact on databases and application performance. When AI is run in the cloud, vast amounts of data must be sent over manufacturers’ networks and stored. This approach can also lead to unacceptable latency, high network bandwidth usage, interruptions due to intermittent network connections, and data security vulnerability.

Another option is to run the AI inference engine on edge computing devices that filter and process data, including making predictions. Since predictions are made at the edge, much less data needs to be sent to the cloud for storage. A small subset of the overall data is sent to the cloud for future AI model training and tuning.

**AI links to enterprise databases**

A major motivation behind Industry 4.0 is to bridge a company’s information systems (e.g., operations, inventory, purchasing, etc.) to provide a centralized view of data across the organization. This requires a convergence of OT and IT infrastructure.

6. Benefits from Applying Open Standards

1. **Economies of scale enabled by standards and open-source software projects**
2. **A pool of shared industry knowledge and best practices**
3. **Access to more solutions vendors**
4. **Less effort and risk to integrate new technology generations**
5. **Faster vendor innovation due to market incentives**
6. **Lower TCO from consolidating existing systems**
4. Understand Software Stack Tradeoffs

AI software development can be rather complex, and deciding how to acquire, deploy, and deliver AI capabilities will have enormous implications on schedules and future scalability.

**Make or buy AI software**

Is it better to develop AI application software in-house or purchase it from a solution supplier?

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**Proprietary or open source AI software**

Is it better to buy AI applications using vendor-owned proprietary software or open source software?

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Intel® Deep Learning Deployment Toolkit

An example of open source AI software is Intel’s Deep Learning Deployment Toolkit, available via the OpenVINO toolkit. It takes a trained model and tailors it to run optimally for different hardware units like CPUs, GPUs, and FPGAs.

For acceleration on CPUs, the toolkit uses the MKL-DNN plugin — the domain of Intel® Math Kernel Library (Intel® MKL), which includes functions necessary to accelerate the most popular image recognition topologies. The toolkits can also utilize the hardware resources of Intel Processor Graphics to provide a significant performance improvement, as shown by the 7.7 times frames per second speedup compared to a baseline shown below.4

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**Monolithic or modular, microservices-based infrastructure**

Is it better to have a single, monolithic system running one AI code base or decentralized computing platforms hosting modular AI microservices?
Map Out Hardware Deployment Model

Although IT departments and operations teams have different requirements and priorities, the IIoT can be used to better converge their systems and satisfy broader corporate goals. As more and more data is generated by an ever-increasing number of sensors and production devices, many manufacturers are finding their data centers and cloud infrastructure are getting overwhelmed.

Shortcomings of traditional data centers
An important consideration is where to process data coming from operations. AI-based algorithms are typically hosted in the data center or cloud due to their high computing and storage requirements, but this approach can have significant drawbacks with respect to:

- Sluggish response: Transmission delay to/from the cloud
- High network usage: Massive data transmitted over the network
- Network security risk: Possible data tampering during transmission
- Reliability gaps: Intermittent network stoppages
- Storage system stress: Vast sensor data volumes to be stored.

The right location to process data
On-location AI processing is emerging as a better alternative for real-time, and mission- and safety-critical manufacturing applications. If possible, most data should be processed locally on a computing device at the edge, and only necessary data should be backhauled to remote computing systems.

Hardware deployment
When developing IIoT architecture, consider the economic and performance benefits from spreading AI microservices across the network, as shown in Figure 3.

Figure 3. IIoT Architecture enable AI microservices across the network

Take a close look at data security
Industry 4.0 and IIoT technologies enable more smart manufacturing devices to get connected and transmit data across networks, but in turn, can also increase a manufacturer's cyberattack surface.

All data is not equal
Since all data is not equal, categorize it to determine which is most confidential and critical to the company and customers. The more valuable the data, the greater the effort should be to protect it.

Keep data local
Data can be better protected when stored on-premises rather than in a third-party cloud or hosted private cloud. Still, the servers and storage devices in local data centers require their own hardware security, like secure boot technology and data-level security.

Encrypt data at rest and in motion
Data encryption is not ‘free,’ but it is a very cost-effective way to safeguard data moving across networks. What about data at rest in a storage device or a computing platform? Encrypted data can impact computing performance because it must be decrypted before use, but with today’s security accelerators, the impact should be negligible.

Data stored on a processor or in a memory system can be susceptible to compromise by sophisticated hackers. However, Intel® Software Guard Extensions (Intel® SGX) on select Intel® processors helps prevent attackers or malware from gaining access and control of the computing platform, applications, and data. This technology (Figure 4) also helps protect critical applications, even when an attacker has physical control of the platform.

5G Private Networks
For a data security boost on the production floor, consider deploying 5G wireless private networks that provide highly secure and deterministic connectivity. Exclusive network access offers greater data protection and privacy than public wireless networks.

Figure 4. Intel® Software Guard Extensions (Intel® SGX) Reduces the Attack Surface

5. Intel and Dell, “Build a Bridge Between IT and the IoT,” April 2017, https://pdfs.semanticscholar.org/9027/83f853053965ffa05f1ce7f18b93bfa8a902.pdf
7. Explore Different Analytics Models

There are many ways to achieve AI. For example, by stringing together a long series of if/then statements and other rules, a programmer can create a so-called “expert system” that achieves the human-level feat of diagnosing a disease from symptoms. In machine learning (ML), a machine automatically learns rules by analyzing a collection of known examples. Machine learning is the most common way to achieve AI today, and deep learning (DL) is a special type of machine learning. The relationship between AI, ML, and DL is shown below.

**Machine learning**

Machine learning is a class of statistical methods that uses parameters from known, existing data and then predicts outcomes on similar, novel data.

**Deep learning**

With deep learning, the algorithm does not need to be told about the important features. Instead, it is able to discover features from data on its own using a “neural network.” When teaching a robot how to perform a task using DL, developers provide the DL algorithm with training data consisting of images or models of the task being accomplished. Neural networks can learn how to perform the tasks by analyzing databases that may have millions of examples.

Currently, DL is mainly used to analyze image and video data, but the technology also can support other types of data.

Why deep learning now

Several developments are enabling a deep learning revolution.

**Bigger datasets:**

The scale of available data has increased dramatically, providing enough input.

**Advanced hardware:**

Training a typical deep learning model requires a huge amount of computing power.

**Smarter algorithms:**

Cloud service providers have realized the value of AI and are investing

8. Act on the Analytics

The pace of innovation is quickening across all industries, including manufacturing and the intelligent factories of Industry 4.0. Unlocking the value of data via machine learning is propelling us into this next phase, and innovations in industrial IoT devices are helping manufacturers continually enhance operational efficiency. Here are some real-world examples of data analytics in action:

**AI Helps Optimize Crop Yields**

At NatureFresh Farms, greenhouse tomatoes grow in a bed of pulped coconut hicks. It is a nutrient-free environment that allows the growers to completely control what goes into the plant. Sensors monitor the fruit’s progress toward perfect ripeness, adjusting light to accelerate or slow the pace of maturation. This kind of farming requires considerable processing power, and NatureFresh Farms uses Intel® Xeon® processors to power its AI algorithms.

**AI Engine Accelerated Inferencing**

Intel, ADLINK, and Touch Cloud are working together to bring inference acceleration to a wide range of industrial and commercial technologies. In this integrated AI solution, ADLINK provides the optimized hardware platform and connectivity; Touch Cloud, the software application and analytics; and Intel, the IoT gateway processor, Intel® FPGA, and Intel® Movidius™ Myriad™ X vision processing unit (VPU), as well as the OpenVINO™ toolkit for smart vision application development. The AI-based solution is compatible with legacy infrastructure, while achieving the benefits of the IoT.

**Robotics Solution Integrates Machine Vision and AI**

NexCOBOT, a NEXCOM company, offers a flexible, modular robotics solution powered by Intel® Vision Accelerator Design products. The solution brings together the insight of AI, the mobility of robotics, and the capabilities of machine vision, providing a new level of precision and optimization for manufacturing and industrial implementations.

**Deep Learning Brings Touch to Robots**

Somatic focuses on adding sensorimotor neural systems and tactile feedback to robotic systems to expand their mapping of the environment beyond visual imagery to include contours, textures, shapes, hardness, and object recognition by touch. The company’s solution, called SenseNet, used Intel’s Reinforcement Learning Coach to help accelerate training and testing of many reinforcement learning algorithms. SenseNet’s API interface is practically the same as OpenAI’s, so integration with Reinforcement Learning Coach was very easy.
MANUFACTURING TECHNOLOGIST

ROI upfront. It's really important to do a proper net present value analysis, so sometimes we found ourselves working on the wrong thing. It's really problematic. Early on, we didn't spend enough time on implementing AI? Any difficulties implementing AI? For some pieces of equipment, our engineers want traceability on how an AI or ML algorithm came up with a decision. In other words, engineers want more of a heuristic decision with an explanation when a defect is detected; so a lack of visibility and understanding into an AI algorithm can sometimes be a problem.

How important are standards? We standardize everything and are active members of a semiconductor standards organization, called SEMI, that has created more than 900 standards for semiconductor equipment. This helps make equipment somewhat plug-and-play, meaning we can use any vendor's equipment for a given process and 95% or more of our software stays the same. As a result, we get rapid time to ramp production because we can get it up and running at peak performance very quickly.

How do you minimize machine downtime? Our equipment is sourced and installed globally, yet we're still able to keep our factories running and, when necessary, quickly fix equipment thanks to remote operations and remote troubleshooting. And Covid-19 makes us more remote. Our remote operations center technicians are now operating primarily out of their homes. In addition, our equipment vendors aren't able to travel, and they now access equipment through other remote technologies.

Open-Source Building Blocks

Open-source software, based on open standards, gives manufacturers the ability to deploy interchangeable solutions, many of which can run on commercial off-the-shelf (COTS) hardware. Here are a few Intel-sponsored, open-source software products for developing IA-based solutions.

OpenVINO
OpenVINO™ toolkit, short for Open Visual Inference and Neural network Optimization toolkit, enables deep learning inference and easy heterogeneous execution across multiple Intel® platforms (CPU, Intel® Processor Graphics) that span cloud architectures to edge devices.13

Intel® Edge Controls for Industrial
This open-source software package accelerates the transformation of industrial control systems to software-defined solutions by delivering a software reference platform with compatible hardware that integrates real-time compute, standards-based connectivity, safety, virtualization, and IT-like management.

Intel® Edge Insights for Industrial
Taking advantage of microservices architecture, this modular, product-validated software enables extraction of edge data (e.g., time series, image/video, and audio) and allows it to be analyzed quickly and securely communicated across different protocols and operating systems.15

Insights from an Intel Manufacturing Technologist

For 25 years, Meyer has been at the forefront of transforming Intel’s semiconductor manufacturing from mostly manual processes towards the goal of complete automation.

Is Intel using AI in manufacturing? Sure. We’re performing predictive maintenance on expensive pumps that move chemicals to the production line, so we save money by servicing and replacing them when needed, and not on a fixed schedule. Some of our vision inspection systems now incorporate AI-based quality inspection, significantly reducing the amount of manual inspection required.

Has AI impacted your databases? By automating our manufacturing, we’ve also unleashed a data explosion that greatly increases data analysis complexity. Our engineers used to review a very manageable amount of trend charts daily, but now the data curve has grown those charts to unmanageable numbers, so it’s like looking for a needle in a haystack. Our new frontier is to have AI algorithms review the data for the engineers and just point out the handful that may be problematic.

Any key learnings from implementing AI? Early on, we didn’t spend enough time on benefits analysis, so sometimes we found ourselves working on the wrong thing. It’s really important to do a proper net present value ROI upfront.

Open Network Edge Services Software (OpenNESS)
This multi-access edge computing (MEC) software toolkit enables edge platforms to on-board and manage applications and network functions with cloud-like agility across any type of network. It also provides the building blocks for various functionalities such as access termination, traffic steering, multi-tenancy for services, service registry, service authentication, telemetry, application frameworks, and device discovery and control.14

Intel® Deep Learning Deployment Toolkit
To utilize the hardware resources of Intel Processor Graphics easily and effectively, Intel provides the Deep Learning Deployment Toolkit, available via the toolkit. This toolkit takes a trained model and tailors it to run optimally for specific endpoint device characteristics and provides a unified API to integrate inference with application logic.15

Intel® AI Analytics Toolkit
The toolkit gives developers, researchers, and data scientists familiar Python* tools to accelerate each step in the pipeline: training deep neural networks, integrating trained models into applications for inference, and executing functions for data analytics and ML workloads.16

Intel® Data Analytics Acceleration Library
This library helps reduce the time it takes to develop high-performance data science applications. Enable applications to make better predictions faster and analyze larger data sets with available compute resources.17

**CONCLUSION**

With the emergence of the IIoT and AI, a new kind of data-driven factory is emerging and paving the way for Industry 4.0. It is not just a ‘smart factory,’ marked by greater machine automation. It is an ‘intelligent factory,’ defined by hyper-agility.

Intel’s flexible solutions, extensive ecosystem, and focus on convergence make it possible for manufacturers to consolidate data and applications at the edge at a lower total cost of ownership (TCO), driving the deployment of intelligence from edge to cloud and helping realize the power and increased efficiency of Industry 4.0.

Companies choose Intel to help them accelerate the development of data-centric, interoperable Industrial IoT solutions so they can seize the massive innovation potential of Industry 4.0 and gain a competitive technological and competition advantage.

**RESOURCES**

Big data and IoT are enabling industrial process transformation. Intel and its ecosystem partners deliver industrial solutions optimized for scalable Intel® architecture, designed to reliably interoperate with the entire industrial environment.

**Intel® Internet of Things Solutions Alliance**

Members of the Intel® Internet of Things Solutions Alliance provide the hardware, software, firmware, tools, and systems integration that developers need to take a leading role in IoT.

**Intel® Edge Insights for Industrial**

Taking advantage of modern microservices architecture, this solution integrates data from sensor networks, operational sources, external providers, and industrial systems, and allows machines to communicate interchangeably across different protocols.

**Intel® Smart Edge**

This multi-access edge (MEC) platform is designed for industrial use cases for on-premise enterprise deployments that require low latency, private mobility, simplicity, and open architecture.

**Intel® IoT Gateway Development Kits**

Intel IoT Gateway development kits enable solution providers to quickly develop, prototype, and deploy intelligent gateways. Available for purchase from several vendors, the kits also maintain interoperability between new intelligent infrastructure and legacy systems, including sensors and data center servers.

For more information about Intel® solutions for industrial automation, visit [intel.com/industrial](http://intel.com/industrial).

Intel technologies may require enabled hardware, software or service activation.

No product or component can be absolutely secure.

Your costs and results may vary.

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