RIT | Golisano Institute for Sustainability
Center of Excellence in Advanced and Sustainable Manufacturing

INDUSTRY 4.0
STARTER KIT

How to get started with digital manufacturing technologies

Manufacturing Operations Software

Machine Monitoring and the Industrial Internet of Things (IIoT)

Data Analytics and Business Intelligence

Automation

The Industry 4.0 Starter Kit

Industry 4.0, the fourth industrial revolution, is already underway. While the third industrial revolution brought electronics and computers into the factory, Industry 4.0 unlocks the power of digital technology to make manufacturing truly smart, data-driven, and connected.

Industry 4.0 leverages recent—and quick-emerging—advances in communications, networking, and computing densities, as well as the ready availability of cloud-based resources. It merges the factory setting with software-based, "intelligent" systems that can extract actionable information from large and complex data sets. In a smart factory, data flows are created and managed to automate manufacturing processes and propel better decision-making in real-time.

Getting started with Industry 4.0 can be daunting, especially for small or medium-sized manufacturers (SMEs) with limited resources. What's more, many SMEs face internal resistance to change and a general inertia when it comes to integrating new technologies with their existing equipment and software. Yet, firms that have overcome these obstacles and put Industry 4.0 into practice have improved their competitiveness and, consequently, their bottom lines.

Harnessing Industry 4.0 rests on two fundamentals: First, an understanding of the tools and technologies that are available to make it work, and, second, the willingness to put in the thought and investment a successful implementation demands. But the payoff is worth it: improved operational efficiencies and product quality, reduced lead times, and other tangible improvements can help SMEs thrive and grow in a fast-changing global market.

How to use this starter kit

If you're ready to begin your journey to Industry 4.0, this playbook is a good starting point. It offers an overview of four core technologies that make up the Industry 4.0 landscape. Within each section, you'll find practical "how to get started" guides that break down some of the most common and high-value applications of each core technology.

To learn more about RIT's Industry 4.0 programs visit: **rit.edu/industry40**

What's inside:

MANUFACTURING OPERATIONS SOFTWARE

Software plays an increasingly important role in driving the use of data to improve manufacturing quality, responsiveness, and operational efficiency. There is a considerable variety of products available to businesses. Navigating the range of options on the market comes down to understanding how different types of software and specific products can impact the key performance indicators (KPIs) for your business.

Enterprise resource planning (ERP) software

Most manufacturers already are using ERP software to help manage their business. ERP systems help to standardize and automate key business processes and also integrate key information into a common database. Many ERP products are designed to support specific manufacturing models (such as contract manufacturing) or sectors (such as food manufacturing). If you are already using an ERP system, you may benefit from expanding your existing system to include more value-added modules, or changing to a new system that provides a greater range of capabilities. An ERP installation can include a range of modules to support key business activities, such as:

- finance operations
- procurement
- customer relationship management (CRM)
- inventory and warehouse management (WMS)
- work- and shop-order management
- labor
- payroll
- productivity tracking
- supply chain management (SCM)
- human resources management

Most often, modules are priced separately as add-ons to a basic package. Companies may also decide to use a standalone software product that specializes in certain business processes, such as CRM and SCM (above).

Other types of software

A variety of different software products are usually needed to manage all the manufacturing processes and data. There is often overlapping data across different manufacturing software systems, so it is important to consider software integration for overall system performance, data integrity purposes, and to reduce redundant data entry. Most often, an ERP software is the center of integration, so understanding how other software integrates with your selected ERP system is critical. Below is a high-level look at other common types of manufacturing operations software used in a digital factory.

- Computerized maintenance-management system (CMMS): Tracks equipment failures and often spare parts inventories, facilitates scheduled and condition-based maintenance.
- Electronic work instructions (EWI) software: Transforms manufacturing work instructions into a digital format that can be accessed from the shop floor. This can overcome challenges of keeping paper work instructions up to date, and also can support collection of shop-floor labor effort by work element, as well as collection of machine or product-quality checks.
- Overall equipment effectiveness (OEE) software: Allows for the collection, analysis, and display of equipment data to support continuous improvement activities.
- Quality management system (QMS): Ties together all quality management processes, including internal and supplier quality, within a single system.
- Manufacturing execution system (MES): Supports integration of data collection and information dissemination across the shop floor. It may include OEE and EWI functionality, as well as shop-floor work planning and scheduling.

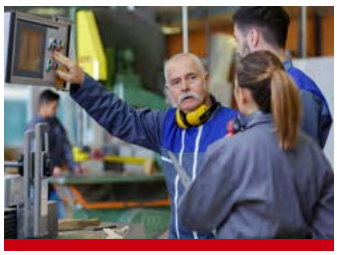
Getting started: Electronic Work Instructions

Electronic work instructions (EWIs) are a cost-effective way to convey complex manufacturing procedures in a user-friendly, easily updatable digital format. Stored on a local network or on a cloud-based server, staff can quickly access EWIs using a laptop, tablet, smartphone, or any other kind of connected device.

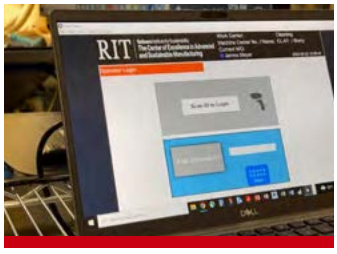
Benefits

A more interactive user experience than paper-based work instructions: EWIs offer a range of formats—from simple text and annotated graphics to video and even augmented reality (AR)—that can serve many different learning styles and training contexts.

Faster, more flexible training: EWIs can dramatically change how new hires and technicians alike learn new jobs, work processes, or tasks. Digital instructions can be optimized for different work settings and can be accessed from a variety of different hardware platforms.



Easy to update, disseminate, and organize: EWIs are ideal for manufacturers with a wide variety of products and are an efficient way to distribute work instructions to operators. A significant benefit of EWI over paper is the ease of change management, and ensuring that operators are using up-to-date work instructions.



The power of data unlocked: Many EWI software products can be used to capture important data, such as operator productivity. Some software products offer EWI capability as part of MES software and support collection of additional information such as product-quality and equipment-state to drive continuous improvement.

Software requirements and functionality

Every EWI system relies on the following core technologies:

- electronic media (e.g., images, videos, and text)
- authoring software
- data connectivity (to Internet or a locally hosted server) across facility
- digital devices

There is a range of software options to allow you to hone in on a solution that matches your specific budget and needs. The graphic below offers a quick glance at what can be achieved using a basic, bare-bones EWI package versus a more advanced, data-driven configuration.

Basic

Any and all EWIs are easily accessible on any digital device.

Selected process data (e.g., lot numbers, component traceability, time tracking, or quality data) can be captured.

Versions of work instructions can be easily updated across multiple facilities.

Advanced

Operator, workstation, and shopfloor performance statistics can be captured and disseminated—including back to operators via EWI.

Data captured by the EWI system can be integrated into business intelligence tools to inform decision-making.

EWIs can be synced with ERP and warehouse management systems to coordinate tasks such as job assignments or material pulls.

Quality-related data collection can be incorporated into the EWI interface.

Technology in Action

Learn how one SME implemented its first EWI system:

Industry sector: Instrumentation sensor technology and process control software

Employees: 150

Challenge: A surge in market demand for the company's high-tech products, which are used to manufacture silicon chips, led to a ramp up in new hires. Training new personnel quickly and consistently to learn complex assembly procedures presented the company with a significant knowledge-transfer challenge.

Objective: The manufacturer decided to explore how an EWI system could streamline its onboarding and training processes in order to meet orders.

Solution: FactoryLogix software

Rationale: After considering a customizable, non-MES EWI system, the firm chose to pursue an EWI package that is integrated into a full MES installation.

Outcome(s): The company intends to begin implementation of the FactoryLogix package in 2024.

Tips for getting started

Infrastructure

- **Local server access:** Depending on the size of your organization and the type of EWI solution you decide to implement, you may need to consider installing a locally hosted server. Hosting onsite requires experienced information technology (IT) staff along with measures to ensure data security. A growing number of products are in fact cloud-based, which may be ideal for companies with limited resources to dedicate to building out locally sited IT resources and infrastructure.
- **Connectivity:** A strong Wi-Fi signal that reaches throughout your factory floor and warehouse areas will help ensure that the EWI system—as well as other digital capabilities—works smoothly and provides a good user experience for your employees. If using a cloud-based EWI product, an Internet connection with a high bandwidth can avoid slowdowns or delays in performance.

Human Resources

- **Training:** Most often, an EWI system does not require dedicated staff to manage or operate it. Products are designed to be used by the same employees who are currently authoring work instructions at your firm. Work instruction authors will require training on the EWI system; this should be included as part of your EWI implementation plan.
- **IT expertise:** If you choose an EWI system tethered to a local network, you will want to be sure that your IT staff are familiar with setting up a server and managing access permissions. If using more advanced EWI features, such as pulling jobs from ERP software, you will likely need staff with expert IT knowledge.

Usability

- **Stand-alone or integrated:** Some EWI products are bundled into an MES, and are often designed for large companies within a narrow industry sector. Though installation and staff training may be a heavier lift, an MES-enabled EWI option could benefit wider digitalization efforts.
- **EWI viewer:** Choosing the right digital devices for an EWI system depends on how your staff work. Personal computers are best for fixed workstations, while portable devices enabled with cameras, like tablets, are better for more mobile working environments.
- **Fixed or flexible layout:** A system can generate EWIs with layouts that are either fixed or flexible. Steps in a fixed layout EWI are chosen from a limited set of template options, whereas a flexible one allows each step's layout to be individually designed.

Comparison of EWI Products

There are many EWI software products available. A cross-section of products were selected for comparison, to represent a broad range of different capabilities and cost profiles.

SOFTWARE *Highlights*	PROS	CONS	HOSTING	UP-FRONT COST*	ANNUAL RECURRING COST*
Dozuki *Short learning curve, ease of content authoring*	Collaboration tools for technicians Process for change history and releases	Limited layout options Continuous scroll format rather than pages	Cloud-based or local server	**$$**	**$$**
VKS *Multiple display formats*	Effective form builder Image-annotating tools	Busy screen layouts No-code environment limits design options	Cloud-based or local server	**$$**	**$**
Proceedix *Visually oriented, with support for smartphones and AR devices*	Business analysis tools	Work process defined by many small steps No photo highlighting tools	Cloud-based or local server	**$$$$**	**$$$**
Tulip *Quick set up, and has some Manufacturing Execution System capability*	Flexible screen layouts Connectivity to other data sources Low-code allows some dynamic functionality	Low-code limits design options	Cloud-based	**$$**	**$$**
eFlex *Supports many product variants and build contingencies*	Flexible widget-based design	More complex implementation pathway	Cloud-based or local server	**$$**	**$$**
FactoryLogix *Includes tools for tracing parts and materials across operation*	Integrated computer-aided design (CAD) viewer Has "light" version for just work instructions	Only Microsoft Windows compatible Light version does not include in-process measurements	Local server only	**$$$$$**	**$$**

Sizing up the costs

The cost estimates in the chart above are based on the software licensing costs for approximately 25 workstations; the cost-scoring rubric is based on the following general annual cost ranges:

< $10,000	**$**
$10–60,000	**$$**
$60–90,000	**$$$**
$90–120,000	**$$$$**
> $120,000	**$$$$$**

Other costs to consider

While the biggest cost will come down to the EWI package you choose to purchase, there are some important technology, infrastructure, and resource investments that you should also factor into your budget:

- digital devices for workstations and mobile work
- Wi-Fi signal improvements
- Internet bandwidth increases (if using a cloud-based package)
- cost of generating EWI content, including porting existing workstation content into software

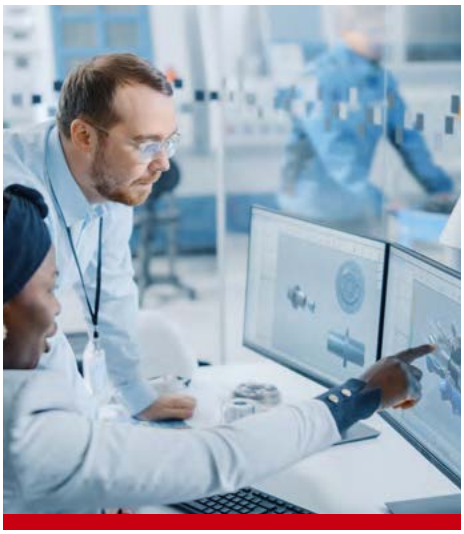
**EWI products vary significantly from company to company, making a direct comparison difficult. The price estimates provided are intended as a starting point for comparison—be sure to contact vendors directly for the most accurate pricing for your size and needs.*

Getting started: Manufacturing Execution System

A manufacturing execution system (MES) is software specifically designed to manage, monitor, and support a company's manufacturing operations.

Benefits

Incredibly flexible: MES packages offered in the marketplace today typically have a wide range of features. Some products may focus on a specific industry, like aerospace, or have strength in a specific functional area, like quality.



Solid foundation for data-driven manufacturing: An MES gives a company of any size the ability to capture input manually or automatically during production. Some solutions feature built-in interoperability with production equipment and off-the-shelf Industrial Internet of Things (IIoT) devices.

Integrated functionality: Increasingly, software packages are available featuring both MES and ERP capabilities. You may find that an extended MES package meets your ERP needs, such as purchasing, accounts payable, and customer invoicing. Similarly, some ERP options may satisfy your MES requirements, such as production tracking and planning.

Software requirements and functionality

An MES platform unlocks a wide range of capabilities that can underpin sizeable boosts in productivity and return on investment, such as the following:

- **data acquisition:** collecting data from across the production process to drive better decision-making and unlock digitalization opportunities
- **scheduling:** shop-floor production planning, machine scheduling, and forecasting of customer availability dates
- **resource management:** allocation of resources to associated production processes
- **process monitoring:** tracking of material movement through production routings, bill of materials, and various inventory stages
- **product traceability:** tracing batch or serialized materials along upstream supply chain, from raw material to assembly
- **quality assurance:** monitoring of quality deviations, exceptions, and non-conformance; and statistical process control
- **document control:** creation and storage of work instructions, drawings, and other control documents that support the production process
- **maintenance:** planning of preventative-maintenance schedules to minimize unplanned production outages

Most MES platforms are now being offered as either a hosted solution or a software as a service (SaaS). The difference between the two comes down to control. Hosted software offers complete ownership to customers, giving them more control over the product and product direction. With an SaaS, the vendor usually manages the infrastructure and product enhancements and upgrades in a way that is consistent between all of its customers.

There are many options when it comes to choosing an MES package that is right for your organization. Consider below a few key differences between a basic option and a more advanced one.

Basic

Focused use: Typically designed to serve a single purpose, such as providing EWIs to aid an operator in performing the production task, or collecting manufacturing-process data.

Advanced

Multiple uses: A variety of process-tracking and planning features are integrated to provide a seamless user experience for both the operator and decision-makers during the production process.

More modular: MES functionality is synchronized with other business tools, including ERP, product lifecycle management, and business intelligence to further enhance the digital thread.

Getting started: Manufacturing Execution System

Tips for getting started

- There are many MES software options. The best platform will depend on a number of factors, such as your available budget, internal staff expertise, and the unique demands your manufacturing operation presents.
- To fully capture the benefits of an MES, make sure that the features of the software that you select are aligned with your business objectives and targeted areas of improvement. Be diligent about understanding feature maturity, user experience, feature roadmap, and the implementation and ongoing support (maintenance) models.
- Remember: Running a complex MES package requires specialized staff for ongoing application support and maintenance that may not exist in your facility today. A small- or medium-sized manufacturer (SME) may want to partner with a third-party firm or the software's vendor to provide adequate and capable resources for both the implementation phase and on-going support.

Technology in Action

Learn how one SME implemented an MES system:

Industry sector: Manufacturer of parts for aerospace sector

Employees: 80

Challenge: Operations management had little visibility of tracking for work-in-progress materials within the plant. The existing traceability system with serialized parts was manual and cumbersome to use.

Objective: The manufacturer decided to explore how an EWI system could streamline its onboarding and training processes in order to meet orders.

Technology solution: Solumina (for manufacturing execution including quality tracking and work instructions)

Rationale: After considering other MES systems the company selected Solumina because of its overall functionality and use within the aerospace sector.

Outcome(s): The company intends to complete implementation later this year.

Comparison of MES Products

The table below offers a high-level comparison of different MES products. Together, they offer a range of benefits applicable to different manufacturing scenarios and business needs.

SOFTWARE	PROS	CONS	FIRST YEAR COST *
Fulcrum	Focused more on smaller manufacturers Some ERP functionality Significant number of integrations	Limited flexibility and features when compared to other MES packages	**$**
42Q	A starter kit for rapid deployment of IIoT technologies included	Lack of an ERP or other accounting package to manage purchasing and other back-office functions	**$$**
Plex Manufacturing	Well-rounded with a full suite of products to manage operations	Plex's ERP and quality management system products not included	**$$**
Tulip	Highly customizable, low-code software Many starter templates to jumpstart implementation included	Additional resources or expertise may be required to adequately build and maintain system	**$**
ECI JobBOSS2	Easy-to-use Good for job-tracking and managing product through a facility Some ERP capabilities A "quote-to-cash" product	Lack of essential features means integrations into other packages likely	**$**

*MES products vary significantly from company to company, making a direct comparison difficult. The price estimates provided are intended as a starting point for comparison for SMEs. Be sure to contact vendors directly for the most accurate pricing for your size and needs.

< $20,000 **$**
$20–60,000 **$$**

Cost considerations

Most newer MES packages offer an SaaS or cloud-based subscription model that lowers the upfront cost. In addition to upfront costs or a subscription fee, you should budget for the following:

- additional end points (e.g., personal computer, tablet, etc.) for capturing data during production
- increased requirements for Wi-Fi access points and bandwidth
- on-going support and product enhancements using either internal or external staffing
- software patching and upgrades

MACHINE MONITORING AND THE INDUSTRIAL INTERNET OF THINGS

Machine monitoring encompasses hardware to collect machine data and software to analyze and display that data. It can be applied to critical production equipment and infrastructure systems and is an important pillar of the Industrial Internet of Things (IIoT).

The Industrial Internet of Things

Industrial Internet of Things (IIoT) is a term that describes a set of technologies that can be used to collect, analyze, and use manufacturing data to improve shop-floor performance. IIoT's namesake—the Internet of Things—was first coined to describe the system of software and hardware for consumer products that facilitates data collection with sensors, public and private networks, and valued-added web-based software. This includes things like your smartphone, a smart thermostat, your doorbell or baby cam, or even smart refrigerators that can place an order at the grocery store. The idea behind IIoT is that a collection of smart hardware, networks, and software capability can bring this type of convenience and value-add to industrial applications like manufacturing and infrastructure (e.g., energy and transportation). IIoT technology is specifically designed for these settings, where high degrees of network security and reliability are essential.

Businesses of all sizes can benefit from the steady stream of new hardware and software that is reshaping how data can be used in the factory environment. On the manufacturing shop floor, access to a network is a critical to IIoT; wireless networks are increasingly being used for this purpose. Cloud-computing leaders like Google, Microsoft, and Amazon all have IIoT software platforms that provide architectures for data management and value-added software deployment.

Examples of IIoT applications in manufacturing include the following:

- asset-tracking during shipping or within a factory (e.g., location, temperature, vibration exposure, etc.)
- glasses with augmented- virtual-reality capabilities to support warehouse operations
- blue-tooth measurement devices that report quality data
- wearable devices that track worker ergonomics or exposure to hazardous materials
- connected machines that monitor product quality as well as equipment health and productivity

Machine Monitoring

Machine monitoring has high value on the shop floor, encompassing hardware to collect machine data and software to analyze and display that data. It allows you to monitor your equipment's operation and uptime, and can give you an early warning when any machinery is not running normally or may be on the path to failure. Machine-monitoring technologies can also be applied to critical production equipment and infrastructure systems, such as air compressors and chillers. Traditionally, machine-condition monitoring is done by a maintenance person who collects data manually. However, such an approach can take significant labor hours and lead to inconsistent results due to human error or simply the inevitable variation in how one technician works compared to another. IIoT technology facilitates machine monitoring, including the connection of equipment of different makes and model years within a single, integrated system. This includes expansion and connection of traditional SCADA (supervisory control and data acquisition) systems, which collect data directly from controllers and PLCs (programmable logic controllers) on your equipment.

A number of machine-monitoring software products are available that provide the basic capability to collect, analyze, and visualize machine data. These can help you better understand equipment utilization across your facility, as well as track data related to machine or process health with an eye to quality. Some directly support condition-based maintenance, which uses equipment data to anticipate when something might go wrong and service would be required. As a practice, condition-based maintenance can dramatically reduce unscheduled downtime on critical equipment, avoiding expensive repairs and disruption to production and shipment schedules. Software vendors may provide their own hardware (often called an "edge device") to interface with equipment or, if not, their product should support a variety of third-party edge devices and standard industrial communication protocols for machine connection.

Getting started: Shop-Floor Visibility

Shop-floor visibility of manufacturing equipment can be achieved by implementing a collection of IIoT technologies. Often working in real time, it allows businesses to track efficiency and productivity and drive continuous improvement. Data collected from operating equipment is at the core of shop-floor visibility and can be used to anticipate costly downtime events caused by asset malfunction.

Benefits

Gives you the big picture: IIoT for shop-floor visibility can provide a detailed overview of your operation, giving you the ability to monitor equipment utilization, as well as overall productivity and efficiency.

Less risk, less stress: Shop-floor visibility helps you identify problems and react quickly. It can reduce downtime and repair costs, especially when coupled with machine-monitoring and predictive-maintenance tools.

More reliable, better data: IIoT helps to standardize how processes and machines are monitored, regardless of process type or equipment vendor. This allows managers to focus on the information that matters most in order to drive smarter manufacturing decisions.

Unlocking data analytics: Integrating data flows from the shop floor with data from key enterprise systems—like quality management, enterprise resource planning (ERP), customer relationship management (CRM), and others—can deliver powerful business-level insights.

Overall equipment efficiency (OEE): An IIoT-enabled shop floor means you can see what's happening as it happens. This provides a common view of important real-time and periodic metrics—including key performance indicators (KPIs)—across your company, from operators on the floor to manufacturing managers and business leaders.

Requirements and functionality

Building an IIoT system to power shop-floor visibility starts with a few basic technologies. An initial IIoT investment supports future expansion into more advanced Industry 4.0 applications. In most cases, shop-floor machinery and processes are linked so that the right information can be collected for analysis. The following technologies are key to achieving shop-floor visibility:

- **Edge devices and connectors** help integrate things like PLCs, even if the equipment is already networked.
- **Operational technology (OT) networks** keep your manufacturing processes safe by creating a shop-floor network, separate from the corporate information technology (IT) network and Internet, thus minimizing the risks of cyber security-related disruptions.
- **Status dashboards and business intelligence tools** enable continuous improvement by providing direct feedback to operators and production managers, and tracking KPIs to enable better, more informed decision-making.
- **Edge gateways** safely connect the shop-floor (OT) network to the rest of the enterprise.
- **Additional sensors** can be added to measure process variables that are not captured by a machine, such as temperature, light, vibration, speed, or other parameters.
- **Operator input terminals** (including frontline execution systems) collect and digitize process information that is often only stored on paper documents, or not stored at all.
- **Time-series databases and historians** can store process data onsite or in the cloud so that you have time-stamped data you can search to make comparisons.

To offer a high-level view of how the above technologies might be deployed in practice, compare the two scenarios below.

Basic

The facility has a network to the shop floor and key production equipment connected.

Equipment status and performance is being stored using existing PLC connections, gateways for legacy equipment, and additional sensors where necessary.

Operators and production managers can use a shop-floor dashboard to view current equipment and production status.

Decision-makers have access to shop-floor trends.

Advanced

The shop floor is integrated into the facility's information technology network, but an edge gateway is used to secure it and isolate it from disruptions.

Sensors and edge-computing devices are added to key equipment to capture machine- and process-condition indicators.

Machine interfaces are added to key production processes to capture operator actions, including process change-overs and in-process quality checks.

Utilization and fault logs for machines are recorded along with condition indicators to facilitate predictive maintenance and minimize unscheduled downtime.

Managers are automatically notified when a problem, such as stoppage, occurs so they can respond quickly.

Shop-floor and enterprise-software data are linked to automatically calculate KPIs for business-intelligence purposes.

Tips for getting started

There are many paths to shop-floor visibility. The best solution for your company will depend on a number of factors, such as your available budget and the unique demands of your manufacturing operation. Below are the most basic elements that any implementation requires.

Human Resources

- **Technical expertise:** Technicians will need to be knowledgeable about installing, setting up, and maintaining PLCs, sensors, and edge devices. Likewise, staff will need expertise in managing OT networks to ensure security.
- **Data analysis:** Dedicated staff (or consultants) will be needed to create and manage dashboards used to visualize data generated by the monitoring system. Some familiarity with interpreting data is required at the engineering and managerial levels.

Culture

- **Shifting to the digital factory:** Shop-floor visibility is an important pillar of continuous improvement and may offer a good starting point for companies just beginning their digital manufacturing journey.

Infrastructure

- **OT network:** Even the most basic shop-floor visibility system requires a means for equipment to "talk" to each other and to communicate with a software program for interpreting data collected while they operate. Separating the shop-floor and corporate networks helps ensure that manufacturing operations are reliable and protected from malware and outages.
- **Connectivity:** An OT network typically requires access to a local server throughout the facility using Ethernet (wired) or Wi-Fi connections. Wi-Fi can have reliability and scalability limitations, and industrial Wi-Fi systems can cost more than running a cabled system, so Ethernet is still preferred.

Technology in Action

Learn how one SME implemented shop-floor visibility:

Industry sector: Food packaging and manufacturing

Employees: Just under 100

Challenge: Critical events on the company's production lines—like downtime incidents—were recorded manually in spreadsheets. In addition, PLC configurations varied considerably between production equipment, making it hard to collect and interpret process data against a common baseline. An existing OEE system was limited to a single data-collection location on the line. Under these conditions, facility managers were unable to identify the causes of production stoppages or take timely corrective actions.

Objective: The manufacturer wanted to learn why its production lines were not running at full efficiency and to develop a system to monitor and display the status (e.g., running, stopped, idle, blocked, or starved) of key production assets.

Solution: An extensive data analysis was conducted of available downtime and line-stoppage data to identify the best process parameters and production assets for tracking progress. A hardware and software framework was developed to facilitate status tracking across the company's diverse equipment inventory, providing dashboards and event notification. This solution was piloted on one production line.

Rationale: By improving the visibility of its busiest line using performance-monitoring tactics, the company set a foundation that can be scaled to the rest of its shop floor.

Outcome(s): The company is now actively piloting the system, collecting production-line data in a consistent fashion that easily lends itself to interpretation. This will help managers to target and address the root causes of downtime and inefficiency, and give them greater confidence in the value of the system as they consider expanding it to other lines.

Comparison of Tools for Enabling Shop-floor Visibility

The table on the next page offers a high-level comparison of different software and hardware tools. The selected products were chosen to address each of the core technologies that a shop-floor visibility system requires: networking; edge data collection and transformation; data storage; and data analytics and visualization.

The specific products and technologies listed below take into account both open-source and commercially available solutions. Technology options are provided for local on-premises technologies, as well as cloud-based technologies for companies that do not want to host and administer local servers.

OT networking is hardware and/or software required for developing a shop-floor network that is secure and isolated from the enterprise IT network and the Internet. This usually requires dedicated switching equipment (Ethernet switches), and at least one router or firewall. Open-source firewalls based on Linux (including software like PFSense) can be part of a firewall strategy, but there are many turn-key, commercially-supported choices for firewalls, switching, and routing.

Edge data collection technologies are required to connect your production equipment to the OT network. Hardware-based or software-only solutions are both options, depending on your equipment. Some edge devices can also do local signal processing or data analysis at the machine to further reduce communications overhead.

Data storage is required to preserve data for future analysis. Storing data requires both a database server and physical storage arrays. For high-volume and -rate data, “time series” databases are best suited. They have size and performance optimizations especially suited to storing time-indexed data.

Analytics software is used to analyze and find patterns in your process-related time-series data. It can also include computation of KPIs. Analysis data can be used to drive business performance through improved decision-making.

Data visualization puts analysis results into tables, graphs, and charts that provide insights to employees across the organization. This is often done through dashboards that quickly convey shop-floor state and productivity, as well as performance metrics in real time. Data analytics and visualization are often provided by the same software, but the range of features for these two capabilities will differ significantly between individual product offerings.

Getting started: Shop-Floor Visibility

Technology options referenced below are products that RIT has previously worked with; they cover a range of levels of capability and cost. There are also many other suitable options in each functional category.

FUNCTION	SOFTWARE/ HARDWARE	ON-PREMISES OPTIONS		CLOUD OPTIONS	
		TECHNOLOGY	FIRST-YEAR LICENSE COST / NRE[3]	TECHNOLOGY	MONTHLY LICENSE COST / NRE[3]
OT Networking *Establishes a secure shop-floor network.*	SW	Linux Firewall	**OS / ****	OT networking is an on-premises function	
	HW	Cisco ASA	**$-$$ / *****		
	HW	Dell Power Switch	**$-$$ / ****		
	HW	Aruba HPE	**$-$$ / *****		
Machine Connectivity *Allows shop-floor equipment to share data across IT and OT networks.*	SW	Node Red	**OS / ****	Machine connectivity networking is an on-premises function	
	SW	PTC Kepware	**$ / ***		
	HW	Maple Systems HMI/cMT	**$ / ***		
	HW	Opto22 Groov	**$ / ***		
Data Analytics *Supports modeling and analysis, and decision-making.*	SW	Jupyter/Python[1]	**OS / ****		
Data Visualization *Displays data on dashboards to provide real-time and historical views.*	SW	Power BI Desktop	**$ / ****	Power BI Cloud	**$ -$$ / ****
	SW	Grafana Server[2]	**OS / ****	Grafana Cloud[2]	**$ - $$ / ***
	SW	Tableau Server	**$$ / ****	Tableau Cloud	**$$-$$$ / ****
Data Storage *Stores manufacturing process-related data in a time-series database.*	SW	TimescaleDB	**OS / ****	Timescale DB Cloud	**$-$$ / ****
	SW	Canary	**$$$ / ****	Canary Cloud	**$$ / ***
	SW	Influx DB	**OS / ****	Influx Cloud	**$-$$ / ***
	SW			AWS Timestream	**$-$$ / ****
	SW			AWS SiteWise	**$-$$ / ****

[1]*Strongest data analytics platform* [2]*Primarily for data visualization* [3]*Non-recurring engineering (NRE)*

NRE SCALE

*	Low level of effort and technical complexity
**	Moderate level of effort or technical complexity
***	High level of effort or technical complexity

ON-PREMISES OPTIONS

First-year license cost

Open Source	**OS**
<$5,000	**$**
$5 - $10,000	**$$**
$10,000+	**$$$**

CLOUD OPTIONS

Monthly recurring license cost

< $250/mo	**$**
$250-$500/mo	**$$**
$500+/mo	**$$$**

Sizing up the costs

The cost of achieving shop-floor visibility can vary considerably, depending on your existing equipment and in-house technical capabilities. As the "Technology in action" example shows (on page 16), visibility can be established using PLCs already installed on your equipment. Often this equipment is not "connected" but can be integrated either by plugging it directly into a system or by adding a machine-side translation device. You might incorporate new technologies, such as additional sensors, to further enhance what you can do when it comes to harvesting valuable process data.

Other costs to consider:

An important cost consideration relates to the expertise you'll need from staff to maintain and optimize a shop-floor visibility system. Take into account the following in your budgetary discussions:

Hardware-related non-recurring engineering costs: As noted above, the cost of connecting equipment to collect data can vary depending on the data available from existing sensors and controllers. Also, if you opt for an on-premises solution there will be additional costs for application servers, data storage hardware, and the associated administration of this equipment.

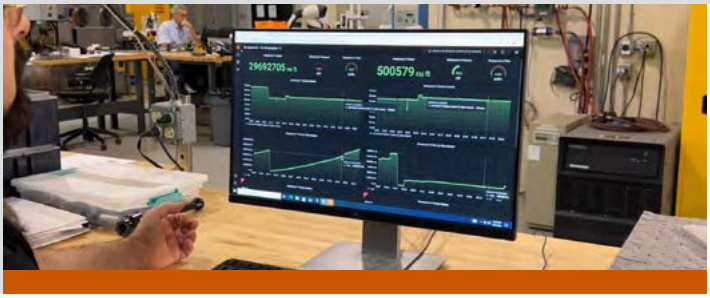
Software-related non-recurring engineering costs: Depending on the products selected, software configuration may be menu-based or, in some cases, require only low-code script (software) development. Turn-key integrated solutions require the least effort, but even these solutions need to be configured for your specific equipment and processes. Open-source solutions have the lowest acquisition costs but typically require a higher degree of software knowledge to implement. There are two major benefits of an open-source, "do-it-yourself" approach. First, you can develop a solution that better suits your needs; turn-key solutions tend to be more "one size fits all." Second, there are no recurring software costs.

Will new staff need to be hired? Skilled technicians are usually needed to set up machine connectivity and IT resources are required to set up OT networks and on-premises servers. Software developers may also be required to set up and connect the various system components. Setting up dashboards and data-analysis processes will require knowledgeable engineers or data scientists. If you have resource gaps, they can be filled by hiring new staff, training current employees, or contracting system integrators to set up the system.

Who will need training? Even if contractors are used, or new staff are hired, existing staff will also need to learn how to use the system. Technicians will need to be able to support maintenance of new hardware. Engineers, production staff, and managers will need familiarity with interpreting and analyzing the data collected from the shop floor. A good rule of thumb to consider: more sophisticated data-analytics and business-intelligence tools will drive more significant benefits, but achieving those will demand greater resources and training.

DATA ANALYTICS AND BUSINESS INTELLIGENCE

Data analytics is a general term that refers to the analysis of data to extract useful information. Business intelligence is a class of data analytics that refers to the analysis of business-level data to extract useful insights.



Data Analytics

The practice of data analytics aims to extract insights from data through pattern, statistical, or trend-based analysis, or though the building of models that represent temporal or variable-to-variable relationships in the data. In the manufacturing context, data analytics can provide different levels of insight, answering questions like the following:

- What is the current state of the manufacturing equipment? (situation assessment)
- Why is this process producing more defects than normal? (diagnosis)
- How will the equipment perform if the production rate is increased? (prediction)

The last two types of analyses diagnostic and predictive, require more sophisticated models and take more effort and skill to develop.

Data analytics can be applied to different areas within a manufacturing organization, but first you must invest in the right tools for collecting and consolidating important data from the shop floor and from across wider business operations. This process is often facilitated by manufacturing operations software and Industrial Internet of Things (IIoT) technologies.

At the process level, data analytics can help identify areas to reduce cost, improve quality and yield, and improve overall operational effectiveness. Becoming more data-driven through the use of analytics tools will eventually allow you to make more informed and faster decisions. What's more, it supports a culture of continuous improvement.

Business Intelligence

Business intelligence, as an analysis practice, focuses on collecting, transforming, and analyzing data to generate reports, dashboards, and visualizations to help you answer your business-related questions. Business intelligence software tools facilitate this process. They can help you pull together data from different sources, such as quality data from a quality management system (QMS), order and fulfillment data from your enterprise resource planning (ERP) system, and revenue and cost data from your financial system. These tools can automate and deploy reports that you are most likely already doing, like key performance indicator (KPI) reporting.

Business intelligence can also help you answer ad-hoc questions that may arise, for example, "Why have costs gone up 15 percent above trend this month?" Business-intelligence software is also often used to help with customer targeting and marketing-related issues.

There are many stand-alone business intelligence software tools on the market, with a wide range of capabilities and cost models. Many products support click-and-drag user interfaces designed for the employee with average computer skills. However, some require advanced programming (i.e., coding), and may require a skilled data scientist for more advanced analyses. Increasingly, business intelligence capability is bundled with other software products, such as ERP software. This is particularly beneficial when the ERP software is being used for most of your business processes or as a means of integrating business data.

Setting up dynamic reporting on shop-floor KPIs can make an organization more responsive to issues that may affect customer satisfaction or business performance. This type of business-intelligence analysis may be offered by manufacturing operations software like a manufacturing execution system (MES), QMS, and even a machine-monitoring application. Another frequently used tool for statistical analysis of shop floor data is Minitab.

Machine Learning

Machine learning is a data analytics tool that can create very sophisticated models that are trained with historical data. Machine-learning methods can be used for many purposes, including: classification or diagnosis (e.g., recognizing a defect in a part or a missing part in an assembly), recognizing and extracting content from text, or for prediction (representation of an expected outcome based on a set of related variables). They can be applied in manufacturing to analyze both shop-floor and business data. Some business-intelligence tools provide basic machine-learning capability, but users need to have some training to effectively use these tools. Many of the tools used by companies like Google and Facebook are now open source and are available as tools within the Python programming ecosystem. However, note that an experienced developer will likely be needed to make use of these powerful tools.

Getting started: Business Intelligence

Business intelligence is the process of using various data analysis and visualization technologies to improve your business's decision-making and overall performance.

Benefits

Informed decision-making: Drive better decision-making by gaining new insights into your operations. For example, data analytics can help companies identify ways to improve key performance indicators.

Immediate cost savings: Accelerate continuous improvement processes to reduce quality defects and scrap, as well as wasted effort and energy use.

Enhanced customer service: Improve service by uncovering customer needs and preferences. Track complaints or identify common areas of dissatisfaction for a unique product, service, or process; or create transparency around the build-to-delivery process to help manage customer expectations.

Software requirements and functionality

A business-intelligence system can be applied to amplify and add power to a range of specific activities, such as the following:

- **predictive maintenance** to avoid costly downtime and improve reliability
- **supply-chain management** to track inventory levels, optimize delivery routes, and identify disruption in supply chain
- **quality control** to monitor quality metrics and identify potential problems to avoid costly rework
- **marketing** to understand customer behavior and target markets, and measure the effectiveness of marketing campaigns and investment

A business-intelligence system is a suite of technologies and tools used to aggregate, store, and process data in a unified and affordable manner. At a very high level, a basic system will include the following capabilities:

- **data sources:** Data can be sourced from a number of operational technologies, such as an ERP platform, an MES, IIoT, or a customer-relationship management (CRM) system.
- **data storage:** The location where data is stored by an integration tool is very often a cloud-based data warehouse. Here, data is processed—cleaned and optimized—and transformed into an easy-to-analyze format.
- **data integration:** After data has been collected from different sources, a data-integration tool is used to load it into a database.
- **data visualization:** Once collected data is stored and standardized by the system, it is ready for decision-makers to use to answer business questions or make predictions using strategies like statistical analysis, machine learning, or natural language processing.

There are many options when it comes to choosing the right business-intelligence package. Consider below a few key differences between a basic option and a more advanced one.

Basic

Data Sources: other enterprise software systems (financial, ERP, CRM, QMS, etc), existing reports

Data Integration: custom scripts, Microsoft Excel

Data Storage: on-premises Microsoft SQL server or Microsoft Access

Data Visualization: Microsoft Excel charts and pivot tables

Advanced

Data Sources: production and infrastructure equipment, real-time interfaces with other enterprise software systems

Data Integration: Keboola, Matillion, FiveTran

Data Storage: Snowflake data warehouse (DWH), Synapse, Redshift

Data Visualization: Power BI, Tableau, Qlik, Sigma Computing

Tips for getting started

While setting up a business-intelligence system may seem daunting, there are many options for leveraging data analytics for your company. The solution you choose depends on several factors, such as your available budget, in-house skillsets, and the unique demands of your operation. Below are additional considerations.

Technology

- **Software as a service (SaaS):** SaaS applications are cost-effective, scalable, maintenance-free (i.e., the vendor is responsible for updating and maintaining it), and secure. Modern data infrastructure is delivered as an SaaS solution.
- **Low-code software:** A type of software that allows users to perform data tasks with little or no coding knowledge. Low-code platforms typically provide a visual development environment with tools like drag-and-drop modelers, smart services, components, and pre-built connectors. They reduce the need to write code—and can be set without a software developer or engineer—and significantly increase the speed at which data applications can be built and deployed.
- **Secure connectivity:** Reliable, high-speed Internet connectivity is a requirement when deploying SaaS platforms. As you rely more on cloud services, security will become more important. Be sure to invest appropriate resources to ensure the security of your infrastructure.
- **"Three Vs of Data":** A term used to describe the fast-growing volume, velocity, and variety of data that describes business in the Digital Age. Companies working with a small data set should opt for a basic business-intelligence system versus a sophisticated one.

Human Resources

Typical data team roles:

- A **data analyst-developer** can help create and maintain dashboards within a business-intelligence system. This role understands a business's goals and is able to convey those as dashboards to support decision-making.
- A **data engineer** can help to set up and maintain the infrastructure that enables data analytics. This includes building and overseeing assets like data warehouses, data lakes, and data pipelines.

Additional hiring considerations:

- **Size and complexity of the business:** A small business with limited data may only need a part-time data analyst. This role may be a shared internal resource or a part-time consultant. A larger business with a more complex data environment may need a data engineer on staff to support the data analysts
- **Budget:** It might be more cost-effective to hire consultants to develop dashboards if the scope is narrow and well defined. Other options include interns and junior-level hires, who may be motivated to learn new skills and grow into the position.
- **Internal skills inventory:** Companies with an internal IT (information technology) team may already have staff with the necessary skills. In addition, low-code data platforms now on the market can help avoid the need for a dedicated engineer, once a common barrier. Third-party vendors are another option to fill in any skill gaps.

Getting started: Business Intelligence

Other tips to consider:

- **Start small:** Don't try to do too much all at once. A good starting point is to target your organization's top three KPIs. A good KPI aligns with one or more business goals and is specific, measurable, achievable, relevant, and time-bound.
- **Get buy-in from stakeholders:** Stakeholder buy-in will help ensure that a new data-analytics project is aligned with your business goals and that the findings are used to make informed decisions.
- **Be patient:** Data analytics is a long-term investment. It takes time to collect, clean, and analyze data. Typically, two types of data-quality issues surface when a company starts to analyze its data for the first time: a process problem or one caused by human error when data is entered. Some technology can help correct these challenges, but, more often than not, the solution will come down to manually conducting root-cause analysis and remediation for data errors.

Technology in Action

Learn how one SME implemented a business-intelligence system:

Industry sector: U.S. manufacturing of parts for municipal water-treatment facilities

Employees: 100

Challenge: Finance leadership faced many manual hours of data manipulation each month to report on sales backlog and closed opportunities. Planning for resources at the factory happened in monthly increments with little visibility into upcoming projects—this created bottlenecks in delivery.

Objective: The firm decided to invest in modern data technology to reduce the manual burden for creating these monthly reports, and to enable new visibility into its operations.

Technology solution: Power BI for visualization, Snowflake for data storage, Keboola for data integration

Rationale: These are highly rated technologies which the integration partner, Cuesta, had prior positive experience with.

Outcome(s): The outcome was a successful set of reports that freed up finance resources and gave better visibility into operations that was previously lacking.

Comparison of Selected Data Analytics Technologies

Technology options for data integration, data storage, and visualization are provided below, along with links to reviews of the technology. There are many software products available on the market in each of the three technology areas, the list below represents a cross-section of options that are commonly used by manufacturers.

CATEGORY	SOFTWARE	REVIEW
Data Integration	**Keboola**	https://www.g2.com/products/keboola/reviews
Data Integration	**Azure Data Factory**	https://www.g2.com/products/azure-data-factory/reviews
Data Integration	**AWS Glue**	https://www.g2.com/products/aws-glue/reviews
Data Integration	**Matillion**	https://www.g2.com/products/matillion-2023-06-26/reviews
Data Storage	**Snowflake**	https://www.g2.com/products/snowflake/reviews
Data Storage	**Microsoft SQL Server**	https://www.g2.com/products/microsoft-sql-server/reviews
Data Storage	**Amazon Redshift**	https://www.g2.com/products/amazon-redshift/reviews
Visualization	**Power BI**	https://www.g2.com/products/microsoft-microsoft-power-bi-desktop/reviews
Visualization	**Tableau**	https://www.g2.com/products/tableau/reviews
Visualization	**Sigma Computing**	https://www.g2.com/products/sigma-computing-sigma/reviews

Other costs to consider

The upfront cost to procure data analytics software tools is not high, but the total cost of ownership can become significant when human resources (e.g., deployment support, training, and maintenance) are included.

Data ingestion, storage, and visualization will require unique talents that may not exist within your organization, and the skillset for these types of technical resources come at a premium compared to other types of software development.

Infrastructure and software licenses will be a fraction of the total cost of ownership compared to the resources required to build and support the platform.

AUTOMATION

An assortment of hardware and software technologies can be used to automate common manufacturing processes to achieve productivity and efficiency gains. Automation is typically used to reduce human labor spent on repetitive or hazardous tasks, and can also be applied to tasks where quality depends on limiting variation in the final product.

There are three basic types of automation:

- **Fixed automation:** Automated tasks that are applied to an entire process line or individual process steps to produce a single product, and are inflexible to change.
- **Programmable automation:** An automated system that can be readily adapted to product modifications through software changes.
- **Flexible automation:** A system that is designed to be quickly changed between different tasks or products.

Robotics and automation

Robots can be deployed in programmable or flexible automation applications. Traditional industrial robots are used with physical or virtual fencing to prevent injuries to human workers. Processes that robots are often applied to include welding, painting, and "pick and place" (machine-loading or assembly tasks). A more recent robotic application is the automated guided vehicle (AGV), which can be used to move materials around in a factory. Warehouse-automation systems are also available that use robots to automatically load and unload inventory or finished goods. Quality-control tasks can also be automated with robotic measurement systems or with computer-vision and image-analysis software.

Many manufacturing facilities today now feature "cobots," or collaborative robots, which were introduced in the early 2000s. Cobots are designed to safely work together with human workers on manufacturing tasks. While industrial robots are available that handle payloads of hundreds of kilograms, cobots handle far less weight (about 10 kg on average).

Administrative automation

Another type of automation in manufacturing involves the automation of manual clerical or administrative tasks through software algorithms (or "bots"). This technology can be applied to external-facing processes like customer-resource and supply-chain management, as well as back-office activities such as accounting, finance, work-order management, procurement, and inventory management. Automated administrative tasks can be fixed (implementing deterministic algorithms) or more flexible (using artificial intelligence to make decisions using incomplete or new data).

Some manufacturing-operations software products, such as enterprise resource planning (ERP) software, have the capability to automate basic tasks. A class of manufacturing software, robotic process automation (RPA) software, automates relatively complex workflows across different software systems and data stores. RPA bots can scrape web data, parse data from emails, copy-and-paste data or files, log into software applications and enter data or initiate another software process, submit orders, and respond to customers. Most repetitive tasks done by humans using software can be automated using RPA bots and can significantly reduce repetitive human labor, eliminate process delays, and guarantee more consistent results overall.

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