CHAPTER 5

IoT Applications in Manufacturing

Detroit, a city in Michigan, was known for adopting the second Industrial Revolution early and thus were at the forefront to adopt the fourth Industrial Revolution before others. Auto companies big or small, use technology to make their production lines more reliable and sustainable. I am calling it technology because most of the workforce in these companies are experienced employees, and they might not know technological terms like AI or IoT. In this chapter, I provide applications of IoT using by these employees unknowingly on a day-to-day basis, to detect and predict mechanical failures on the manufacturing line.

This chapter provides use cases for managers to explain to unions, to make them understand how helping workers adapt to new technologies will reduce layoffs and provide workers the opportunity to survive and even thrive using these technologies. IoT is set to revolutionize the manufacturing industry in terms of its operational efficiencies through predictive maintenance and optimized production lines.

When things broke down, you would go out and fix them; this is called reactive maintenance. Predictive maintenance is one of the areas that benefited most in the manufacturing industry using machine learning algorithms. It focuses on how to predict when certain conditions are going to occur and when machines will fail. Later this chapter covers the application of IoT in exploring the capabilities of Azure IoT predictive maintenance. We discussed IoT Central in Chapter 3, and I will be using a preconfigured solution that comes with IoT Central.

Later we will discuss predictive maintenance, one of many IoT use cases that managers have had difficulty integrating into their existing operational technology and legacy machinery. Finally, we will also cover the benefits of doing so.
How do you motivate hardworking, loyal employees with years of experience in manufacturing to use new technology? Companies are aware of these challenges, and to implement technology at the enterprise level, they started slowly with awareness, training and showcasing the capability of one good product at a time. Let’s take the example of an everyday worker on a shop floor. He digs through an unorganized mess of tools laying all over the floor. He then sets out on a walk around the shop floor, searching workstations for the tool and interrupting other team members to ask if they’ve seen it. As a manager in your company, would you go and explain machine learning and AI to those working on the production floor? No, but what if you were to go with an augmented-reality-enabled wearable device and help that worker search for that part he was looking for? This will remove anxiety and fear about machine learning, AI, and these advanced IoT technologies.

I remember in 2001, one of my internship projects in a multiproduct company was to design and automate a process to sort emails and assign customer complaints to the relevant department. At that point, this job was done by two people manually. There was no popular email provider and the company had its own email server set up in-house. I got access to the directory (MAPIFolder) where each incoming email was dropped as a file. I designed and implemented a simple system in Visual Basic 6, with a file reader (InboxItems), reading the body of the email using MailObject, and searching for product names in content. Based on the product name matched in the email body, I assigned the mail to a respective department. The database I used was Microsoft Access. I did it to eliminate repetitive work using a custom algorithm. As a manager, your task is the same: getting rid of repetitive work, proving the advantages of technology, and allaying the fears of your workers. In manufacturing, there are repetitive tasks that can be easily automated.

We use these advanced IoT technologies not only because we need increase profit, but also to meet strict quality management standards. Think about food factories, following strict food safety guidelines. Using paper or multiple spreadsheets is a labor-intensive process and creates risk. This industry must rely on the cloud and AI cognitive services to meet guidelines and gain the confidence of its customers with zero error tolerance. Tetra Pak, the largest supplier of food packaging, produces 600 data points per piece of equipment with high frequency. That’s too much data for any human to analyze in real time.
Blurring geographical boundaries to take advantage of time differences and competitive workforces is another reason we need IoT. Senior executives need to oversee and monitor the manufacture of pipeline seating in the Pacific Northwest of the United States, although the actual manufacturing line is in Shanghai, China, some 5,700 miles away. The need to view real-time information and insights is crucial, for both the headquarters as well as for plant managers in Shanghai. Without any IoT implementation, data need to be fed into spreadsheets. By the time this information reaches the executives, the data are old and not always actionable. With monitoring of machines, process and production managers now look for patterns, relationships, and causality across the plant with greater speed, accuracy, and efficiency to develop better solutions for building products and improving yields.

Another pushback we saw from employees and unions was in regard to job security. The Wall Street Journal reported that technological change sweeping the auto manufacturing industry was forcing job cuts. Any kind of automation always got a slight reprieve from the accusations that it has been the key driver in job losses, in the United States and in other countries as well. I certainly agree that no company fires a worker for fun. Sometimes we introduce automation into a task that no one really wanted in the first place. Companies first try to train the talent they have, upgrade their knowledge, and then move them to different department. If nothing works out, the final option is job loss. Of course, embracing robotics allows companies to reduce costs, but it actually frees the employees to do something that cannot be done by robotics, perhaps opening new opportunities. Technology might help create new job categories. Humans are not replaceable with automation. You should stop thinking about whether technology led to a loss of jobs, and instead focus on how to facilitate the transition of your employees into new job opportunities.

Today, every industry makes worker safety its highest priority. Did you notice how many employers either allowed their workers to work from home or closed locations completely during the 2020 COVID-19 outbreak? Similarly, managers keep a close eye on dangerous jobs, machines, and locations listed as red flags. Their top priority is to have zero accidents. Often the reasoning behind implementing robots is a desire to replace human laborers performing dangerous tasks. Working with high-speed machines, being in the presence of poisonous gases, and moving forklifts are all safety challenges. Think about a company that frequently has major accidents and another company with no major accidents in the last year. Which one would you join? Safety attracts good talent, and helps in retaining talent. In the current world, customers are conscious, too. They would like to purchase goods and services (do business) from a company that is moral and socially responsible.
Applications

Some of the common applications of IoT in manufacturing are predictive maintenance, asset tracking, and energy management. The IIoT platform has proven its importance in uncovering process and workflow inefficiencies in industry. The most common feature we learned about is data analysis and usability, but the most important feature is security, including access management, security patch updates, and device authorization. These are the most prominent applications of IoT in manufacturing to directly improve shop floor productivity.

We will be covering logistics and supply chains in detail in Chapter 9. I will not discuss further the obvious advantages of IoT in manufacturing, which you already know about, like increasing productivity and efficiency and gaining a deeper insight into customers’ behavior patterns and needs. The following are other essential use cases to help explain the applications of IoT in manufacturing plants.

Use Case 1: Unlocking Innovation

In the introduction to this chapter, I proposed that technology might help create new job categories and automating repetitive tasks could free up employees to think about product innovations. Many companies invest in events like hackathons (or hackdays, hackfests), a design sprint-like event where all employees are asked to think differently. This concept started in the IT industry with computer programmers, but it has crossed industrial boundaries. By the end of an event, a team comes up with new product idea, existing product improvement, patentable technology, or solution to any existing small or big problem in their department. Companies benefit from these events and therefore reward winning teams with incentives.

Recent innovations using IoT have occurred in the mining industry. RTVis™ (Rio Tinto Visualization) is a trademarked information system used to automate every aspect of mining. The mining engineers and technicians are seated in a control center complex in Perth, Australia, remotely guiding the mining operations of an iron ore mining site in Pilbara, Australia. The control center is connected to driverless trucks and trains, autonomous drill machines, and guiding loading and unloading of the ore from the mining site. The system controls multiple drills using sophisticated algorithms. The biggest advantage is managing controlled blasts using data from sensors and deep learning from past blasts.
There have also been innovations in human–machine collaboration. For example, retail warehousers like Amazon and Alibaba have added robots in their warehouses to help with the logistics of locating products and bringing them to workers, rather than having employees go to the shelves to hunt for products. In this case, people work along with the army of robots to cut operating costs.

Use Case 2: Subscription Economy

You pay monthly for Netflix and Spotify subscriptions because they align with your phone and Internet utilities, which you pay for monthly. Customer now, however, also like to subscribe for goods for which they think they know the consumption cycle, like soap, shampoo, or milk. When you subscribe, these things will get delivered at your configured preset intervals. This type of shopping is different than traditional retail, and is known as a subscription economy. Taking it to the next level, for a flat $1,500 monthly fee, a Cadillac customer can swap out his or her car up to 18 times per year. The fee covers all registration, maintenance, and scheduled repairs. Now let’s talk about the manufacturing industry in this growing subscription economy:

Kaeser Kompressoren, a German manufacturer of air pumps, compressed air dryers, and filters, is now offering IoT digital twins: product and services. The company has added sensors with their products, which send data back to the company’s data center in real time. These data are then used to offer predictive maintenance. The company calls it Air-as-a-Service (AaaS). Customers are happy because they are saving money in unnecessary visits from Kaeser maintenance team, and they receive productive visits when compressors are actually about to shut down. Any shutdown is bad for business. Caterpillar is similarly adding sensors to its heavy equipment to suggest when parts need replacing, including air filters. The company is making good amount of money from this offering and dispatching original equipment manufacturer (OEM) parts.

For airlines, Rolls Royce is now charging its customers by the hour instead of an upfront capital cost. Customers pay by the hours an engine runs in an arrangement called engine as a service. This is generating a continuous revenue stream for the company, and small customers are happy. More than 25 sensors track engine health data and fuel usage to uncover data insights that will enable airlines to improve operational performance and fuel efficiency. Along with this, Rolls Royce added a maintenance as a service offering: They would take over all the upkeep and life cycle management of the engines. Again, customers are getting the advantages of not keeping records of
scheduled maintenance and also having maintenance done at any location offered by Rolls Royce. This reduces operating costs, slashes engine downtime, and lengthens the average life of its jet engines. A key driver of competitive advantage for Rolls Royce in the IoT-enabled engine industry is the first-mover advantage associated with collecting and using customer data to optimize its other products and services. For example, the company is rolling out the same service for its luxury cars connected with IoT data capabilities, which is different then the current car leasing business model.

Use Case 3: Predictive Maintenance

Predictive maintenance is a popular application of predictive analytics that can help businesses in several industries achieve high asset utilization and savings in operational costs. The most visible concept of predictive maintenance is using connected sensors to monitor maintenance needs in the manufacturing industry. Companies traditionally used manual logs, past experience, and manufacturer recommendations. Under that model, sometimes parts were replaced even though they were working fine and still had life left. On the other hand, sometimes parts broke down before expected, shutting down production. The IIoT takes networked sensors and intelligent devices and puts those technologies to use directly on the manufacturing floor, collecting data to drive three levels of maturity.

Level 1: Sensors help in reactive maintenance. If a machine goes down, connected sensors automatically pinpoint where the issue is occurring.

Level 2: Predictive analytics.

Level 3: The next level is autonomous self-healing.

Predictive maintenance has several benefits, including these:

- Reduce maintenance costs
- Avoid unexpected failures
- Improve repair and overhaul time
- Optimize spare parts inventory
- Increase in uptime
We discuss more about this use case using implementation in the lab section of this chapter using Azure IoT Solution Accelerator. Common predictive elements a manager needs to know are the following:

- **Life**: Time the equipment has left until it fails.
- **Probability**: Probability of failure.
- **Breakdown point**: Likely component of a given failure.
- **Risk level**: Equipment risk ranking.
- **Maintenance recommendation**: Given a certain error code and other conditions, maintenance steps, tips, and manufacturer’s recommended solution.

We are not using any real device here, because there is no easy way to plug your customer sensor or device into this preconfigured solution accelerator.

**Lab: Predictive Maintenance**

Modern aircraft engines are equipped with highly sophisticated sensors to track their functioning. By combining the data from these sensors with advanced analytics, it is possible to both monitor the aircraft in real time, as well as predict the remaining useful life of an engine component so that maintenance can be scheduled in a timely manner to prevent mechanical failures.

We also need a visualization dashboard, so that aircraft technicians can monitor the sensor data from an airplane or across the fleet in real time and use visualizations to schedule engine maintenance.

In this lab I am using a prebuilt solution that can be provisioned from the Azure Solution Accelerator portal by navigating to https://www.azureiotsolutions.com/. Log in and click My Solutions, then click Create A New Solution. Select the Predictive Maintenance solution box and use the wizard to set the solution. We went through this in detail in Chapter 3. Enter a solution name (I chose PredictMyMaintenance), select Subscription, select a region, and click Create. The Create button launches a workflow that will deploy an instance of the solution within a resource group in the Azure subscription you specify. The next screen, shown in Figure 5-1, will show you the resources this solution is provisioning.
When the deployment to your Azure subscription is complete, you will see a green checkmark and Ready on the solution tile. You can now sign into your Predictive Maintenance solution accelerator dashboard. The data source of this solution is comprised of an emulated data set stored in a .csv file in Azure Blob storage.

**Azure Resources**

As shown in Figure 5-1, the Predictive Maintenance solution accelerator is provisioning these resources.

**Storage Account**

This is a multipurpose storage account. It stores data for predictive experiment files to manage partitions of the Event Hub processor, keeps telemetry data from the devices, and keeps device simulation data (these are temporary data if a project goes live and is connected with real devices) and data to visualize on the dashboard generated from webjob and Stream Analytics.
Along with this storage account, creating resources in Azure also creates two storage accounts. The first storage account contains two containers: `simulatordata` and `<yoursolutionname><random alphanumeric>`. The simulator container is dedicated to storing training data sets, test data sets, and experimental outputs. The same container also has four tables. Azure Table is the fastest, cheapest, most queryable (in this scenario) solution.

- **DeviceList**: Contains registered devices.
- **Devicemlresult**: Contains result data that come out of the Machine Learning job.
- **Devicetelemetry**: Contains all the device data that are coming in through IoT Hub. It is populated from the Stream Analytics job.
- **Simulatorstate**: Contains the state changes of the simulators, which is read by the Web app.

The second container’s name is matched with the eventhub name and contains eventhub’s data.

### Functions App

This contains several functions to be called from the next stages of the deployment, as shown in Figure 5-1; for example, to perform a microtask, such as `createAADApplication`, `createServicePrincipal`, `generatePassword`, `getMLStorageLocation`, `setupMLWorkspace`, and `uploadFileToStorage`. The output of all these functions is stored to the storage account created previously.

### Azure Resources

This next step will create several Azure resources, as shown in Figure 5-2. It deployed two app service plans: `<yoursolutionname>-plan` and `<yoursolutionname>-jobsplan`.

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**Note**  By default, systems deploy them with a P1 plan. This is a costly plan—around $200 per month. The first thing you need to do is open it, click Scale up, and change it to the F1 Free plan or D1 shared plan. Similarly, do this for the Functions app, too.
It will give you a warning that the Always On feature is not allowed in the target compute mode. Open App Service, navigate to Configuration, click General, and toggle Always On to Off.

### Event Hub

The Event Hub is internal to the solution, used to manage data queues. It collects, rapidly transforms, and processes large amounts of information, and uses partitions, which define how many concurrent consumers and producers can access the data pipeline. Similarly, in this solution Event Hub receives preprocessed telemetry data, processes it, and saves it back to storage. When you are working with high volumes of data that just cannot get lost, this is essential.
**IoT Hub**

IoT Hub is the ingestion point where the data from the simulated plane come into the system. It receives the actual raw data from devices. All device management tasks are facilitated by IoT Hub. Similarly, in this solution IoT Hub has four devices registered. To see the registered devices, open IoT Hub and click IoT Devices under Explorers.

**Stream Analytics**

By now you know Stream Analytics is a real-time cloud stream processing offering, designed to analyze incoming data to get real insight on the process being monitored. Similarly, in this solution, the stream analytics is provisioned with the name `<yoursolutionname>-Telemetry`. To analyze the different steps in this, open it and click Job Diagram under Support + Troubleshooting.

As shown in Figure 5-3, the Stream Analytics job has one input, **IoTHubStream**, and two outputs **Telemetry** in Azure Table Storage and **TelemetrySummary** in Event Hub. The analytics job queries the data stream from the IoT Hub to extract sensor data, which are subsequently stored in the Telemetry data table. Additionally, the Stream job calculates the average sensor data using a sliding window and then passes the resulting summary data to the Event Hub.

![Job diagram of Stream Analytics](image)

**Figure 5-3.** Job diagram of Stream Analytics
Use the following query to calculate the summary with a sliding window.

```sql
SELECT
    DeviceId,
    Cycle,
    AVG(Sensor9) AS Sensor9,
    AVG(Sensor11) AS Sensor11,
    AVG(Sensor14) AS Sensor14,
    AVG(Sensor15) AS Sensor15
INTO [TelemetrySummary]
FROM [StreamData]
GROUP BY
    DeviceId,
    Cycle,
    SLIDINGWINDOW(minute, 2)
HAVING SUM(EndOfCycle) = 2
```

The query of `telemetrySummary` as shown here calculates the average of sensor data within a specific period of time and engine cycle. There are three types of windows available.

- **Tumbling window**: This uses a fixed size, nonoverlapping series of events.
- **Hopping window**: This uses a fixed size but overlapping series of events.
- **Sliding window**: This outputs a series of events only when the values within the window actually change, enter, or leave the time window.

### Machine Learning Studio Workspace

Azure Machine Learning is used to make predictions on the remaining useful life (RUL) of aircraft engines given the inputs received. To see your ML Workspace, you must go back to your solution. Navigate back to [https://www.azureiotsolutions.com/](https://www.azureiotsolutions.com/), and click My Solutions, then click the solution you created. You will see a link to your ML Workspace. This will take you an Azure ML portal at [https://studio.azureml.net](https://studio.azureml.net).
Every Machine Learning model has these steps common, having a training set, test set, and actual data to be evaluated. These three inputs are shown in Figure 5-4. These data are preprocessed using R-Script for removing bad data, creating metadata. You can see these scripts by clicking these boxes. Once the data are preprocessed, they are used to train two machine learning regression models: decision forest regression and boosted decision tree regression. Subsequently, the models are scored and evaluated using the test data. The training data set is used to train two models, which are then evaluated and used to predict RUL.

There exists another experiment, Remaining Useful Life [Predictive Exp.]. This is the actual web service that performs the remaining steps of the first experiment model (i.e., score model) and contains web service input and web service output nodes. You can call this web service manually with data to see the output score of the trained model. To see the test data, you can use the properties window or enter data manually.
Solution Dashboard

You can open your solution dashboard by navigating back to https://www.azureiotsolutions.com/. Click My Solutions and then click the solution you created. You will a Go To Your Solution Accelerator link. This will display the dashboard shown in Figure 5-5.

Notice the aircraft design with two engines on the left half of the page and various telemetry data from sensors on the right side of the page. The RUL comes from the Machine Learning model, which uses simulated sensor data to calculate when engines are expected to fail.

On this dashboard, there are two sensors installed in each engine. They are labeled sensor 9, sensor 11, sensor 14, and sensor 15. Sensor readings are captured every half-hour during each flight, which lasts from two to ten hours. The total flight duration is denoted as the cycles. We can see data coming from the engines directly in the Azure storage.

The full simulation takes about 35 minutes. The 160 RUL threshold is met for the first time at around five minutes and both engines hit the threshold at around eight minutes. The simulation runs through the complete data set for 148 cycles and settles on final RUL
and cycle values. You can stop the simulation at any point, but clicking Start Simulation replays the simulation from the start of the data set.

Now it is time to see some data and overall, the solution working. Click the blue Start Simulation button. You will see “Starting” for couple of minutes, as the system is cold booting before you see sensor readings and the calculated RUL as shown in Figure 5-6. To see the warning, you need keep the solution running for about half an hour, the time engine data takes to reach to the critical stage.

![Figure 5-6. Solution Acclerator dashboard with warning sign and calculated remaining useful life (RUL) from the Machine Learning model](image)

When RUL is less than 160, the telemetry section displays a warning symbol next to the RUL display. The solution portal also highlights the aircraft engine in yellow. Notice how the RUL values have a general downward trend overall but tend to bounce up and down. This behavior results from the varying cycle lengths and the model accuracy.

You can stop the simulation at any point, but clicking Start Simulation replays the simulation from the start of the data set.
Note If you haven’t scaled down your app service plan, then delete the resources. Your free credit will be used within 24 hours. If you no longer need the solution accelerator, delete it from the Provisioned Solutions page by selecting it and then clicking Delete Solution.

For advanced readers, skilled in programming, Microsoft also provides the full source of this solution on the GitHub repo at https://github.com/Azure/azure-iot-predictive-maintenance. Going through the code is outside the scope of this book.

Benefits of Using IoT in Manufacturing

Manufacturers and industrialists in every sector have a significant opportunity at hand, where they can not only monitor but also automate many complex process. Although there have been systems that can track progress in the plant, IIoT technology provides far more intricate details to managers. The following list highlights a few key benefits.

- **Increased safety:** By implementing AI in machines using IIoT, a data analytics system can inform employees immediately of issues. By analyzing data over an extended period of time, long-term exposure can be calculated, and potentially hazardous conditions can be detected in advance. Monitoring the number of injuries, illness rates, near misses, short- and long-term absences, vehicle incidents, and property damage or loss during daily operations ensures better safety and working conditions.

- **Reduced costs:** Managers are aware of the potential to save money and increase profit through the adoption of IoT, but how and where is always a challenge. The answer lies in cost savings in repairs, number of breakdowns, and total labor cost saved from manual checks. I agree that not all machines require sensors. You have to do a cost-revenue analysis. Hence, start with one machine and a few sensors and build the enterprise-level project based on learning and your company specific key performance indicators (KPIs).
• 24/7 production: By using autonomous processes, you can reach 24/7 production with limited human oversight. Self-dependent systems provide resilience to industries and help them to achieve a faster time to market. Faster and more efficient manufacturing and supply chain operations allow for reduced product cycle times. This shorter time to market gives you an edge over competitors and first market advantage.

Challenges of Using IoT in Manufacturing

The toughest challenges enterprises face in starting IoT-enabled digital transformation initiatives include uncertainty about the return on investment (ROI), data security and privacy issues, the lack of qualified employees, and integration with the legacy systems. Let’s look into the key challenges.

• Large investment needs and uncertainty about the ROI: IoT initiatives incur several investments like procuring hardware, adding connectivity, adding cloud storage, and technical support. Business managers need to know how quickly they can roll out new solutions and how quickly a solution will start generating revenue. Large hardware costs sometimes bring down quarterly results and convincing shareholders to undertake such an infrastructure expense is difficult without taking a hit on share price.

• Data security issues: IIoT adopters believe IIoT is increasing the risk of cyberattacks. We talked about this in detail in the first few chapters.

• Lack of qualified employees: It is a hard truth that businesses have a shortage of people at the management level with experience in IoT. They were running businesses traditionally for decades and don’t want to invest the time to learn about new technologies due to their busy schedules. Lack of skilled employees is another side of the same issue. Specific skills that are lacking in employees include data analytics, experience in big data, IoT sensors and devices, IT security, and AI.
Integration with legacy systems: The difficulty of rolling out IoT solutions in manufacturing ecosystems is integrating information technology (IT) and operational technology (OT) without data losses and security inconsistencies. Ensuring seamless convergence between IT and OT is difficult because in the past, the systems had different objectives, so they were built based on different technologies and networks.

Exercise

You can practice other preconfigured solutions from the same portal; for example, deploy Connected Factory. This solution is my favorite because it is directly related to manufacturing. This solution includes industrial device interoperability, remote management, and Azure Time Series Insights. Benefits of this solution include the following:

- **Visibility across your manufacturing operations**: Make more informed decisions with a real-time picture of operational status.
- **Improved utilization**: Maximize asset performance and uptime with the visibility required for central monitoring and management.
- **Reduced waste**: Take faster action to reduce or prevent certain forms of waste, thanks to insight on key production metrics.
- **Targeted cost savings**: Benchmark resource usage and identify inefficiencies to support operational improvements.
- **Improved quality**: Detect and prevent quality problems by finding and addressing equipment issues sooner.

For advanced users, the code for this solution is available at [https://github.com/Azure/azure-iot-connected-factory](https://github.com/Azure/azure-iot-connected-factory).

Summary

In the 2016 presidential election, automation and robotics got a slight reprieve from accusations that it has been the key driver in job losses in the United States. We discussed the other side of this accusation and why it is important to automate repetitive
and dangerous tasks. Investments in education and training by both employers and employees helps retain valued employees and use their experience in new roles, innovating new products and services and thus generating new revenue streams.

We discussed various use cases that are different from traditional use cases in the manufacturing industry. We discussed how investment in hackathons can unlock new opportunities. We also discussed the subscription economy.

Finally, we explored the capability of Azure IoT Solution Accelerator using predictive maintenance preconfigured solutions. Predictive maintenance is the algorithm to determine unscheduled equipment downtime in the future. I started by creating a solution, and then I analyzed its components and Azure resources like Storage, Stream Analytics, and Event Hub, which are all offered by Azure. Finally, I explained how telemetry data is generated by the simulator serverless webjob. We also explored various sections of the dashboard.