1. AI for Manufacturing

Learning Objectives:

By the end of this chapter, readers will be able to know:

1. Industry trend on AI applications for manufacturing
2. Evolution of industries
3. Industry 4.0
4. Application of AI in large scale manufacturing
5. Application of AI in energy sectors
6. Factors hindering the application of AI in manufacturing industry

1. Global trend in use of AI

Today, most industries are adopting AI for their profit. Many companies are trying to develop new solutions, services, and products for use in manufacturing plants. Here is a chart that shows how the top global manufacturers are implementing AI.

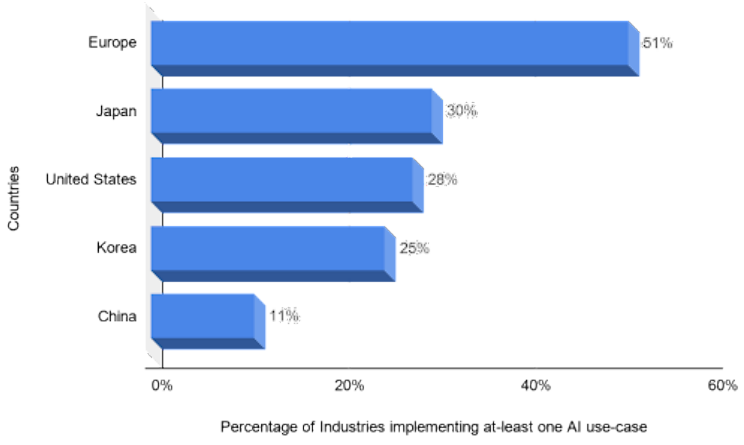


Figure 1:Global Trend in Implementing AI

The chart shows the statistics published in 2019 by the *Capgemini research institute*. Their research in 300 major manufacturers found that Europe is leading in the implementation of AI in their manufacturing process.

Germany was found to be leading the pack, with 69% of its manufacturers implementing AI within Europe itself.

All combined, these countries/regions represent manufacturers with $3.8 trillion of annual revenue among the top 300 manufacturers.

Resources:

- *CapGemini Research paper*

2. Industrial Evolution

Industries that we know today did not come in a single day. It evolved from a simple manufacturing process to the elaborate manufacturing process that is used today.

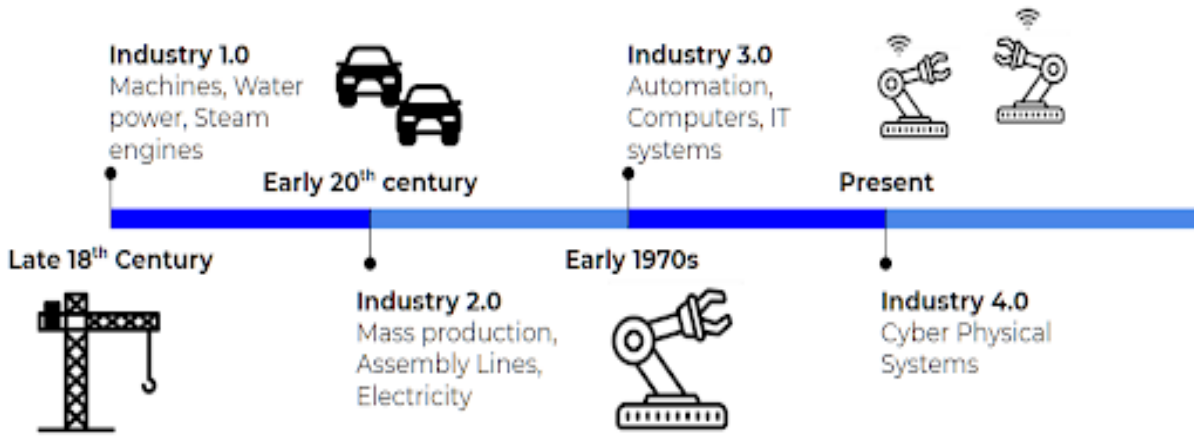


Figure 2: Industrial Revolution Phases

Till the late 18th century, all the industry ran on pure human and animal strength. There was no reliable source of power to run heavy machinery; hence the existing machines were relatively simple and could not produce in high volumes.

With the development of steam engines and the ways to harness the running water's energy during the late 18s century, Something great started taking pace. It was called the beginning of the industrial revolution. Companies started developing Heavy machinery for the large volume production.

With the turn of the 20th century, the industry trend started to shift in a new direction. Henry Ford revolutionized the assembly lines' concept for the mass production of Ford Model T. This trend was named "Industrial revolution 2.0". Electricity started to run the heavy machinery because electricity became cheaper than the then-popular power source like coal and gasoline.

Until the late 1960s, industries were using manufacturing techniques half a century old with slight variations; during the early 70s, computing advancements started to take pace. IBM had a breakthrough in developing microprocessors for the manufacturing industries. With capable computing devices, industries started to integrate those into the production plant.

The production system started to become automated. Computers started to take over the complicated and tedious jobs like welding, painting, etc. large companies started developing IT systems to aid the production. This trend was named "Industrial revolution 3.0."
In 2010, there was a new trend in the manufacturing industry. Now the talks are about virtual reality, 3D printing, robotics, AI and the internet of things.

Resources:

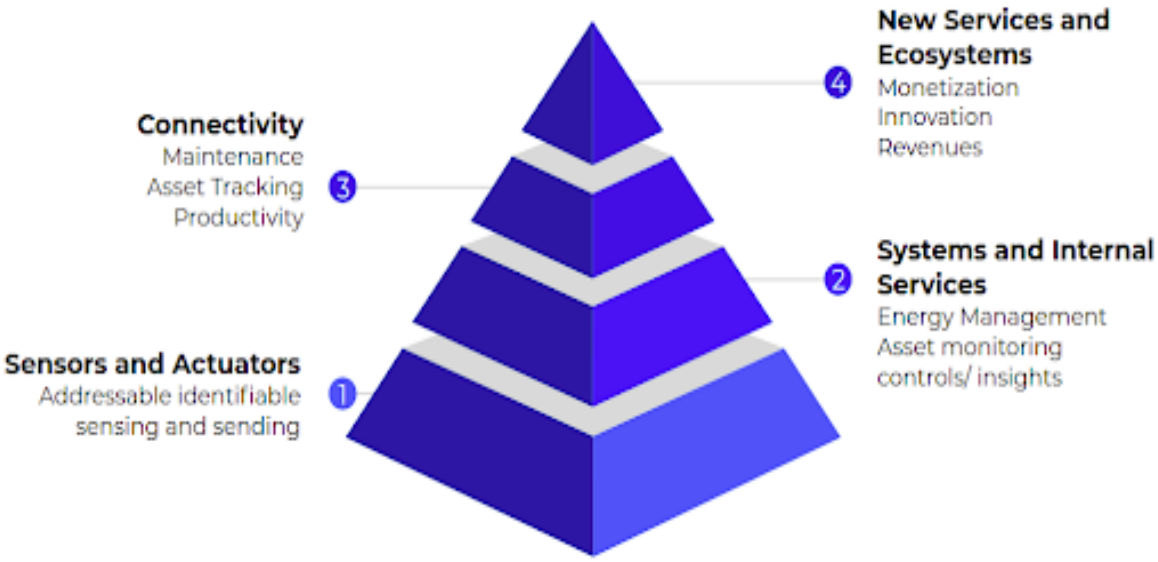
- *Implementation of AI in Manufacturing*
- *Software House That Helps You Innovate - Neoteric (2020)*
- *Industry 4.0*
- *L. Columbus: Forbes (2020)*
- Landing.AI NanoParticle detection
- Microsoft's 2019 manufacturing trend report

3. Industry 4.0

Since our primary focus is on using AI in manufacturing, we will discuss a bit more on "Industry 4.0".
Short speaking, industry 4.0 is all about connectivity. Let's consider a factory where most of the work is done by robots in several departments. The idea behind industry 4.0 is that every robot is interconnected and can communicate with each other to improve productivity significantly.

Figure 3: Industry 4.0

Industry 4.0 is not just a bunch of automated and communicating robots. There are simulation practices, the "Internet Of Things" to keep every machine connected, cybersecurity to secure the communication data, cloud computing. "Additive manufacturing", augmented reality, and many more.



While implementing industry 4.0, we have to think about four aspects.

"Sensors and Actuators,"

"Systems and internal Services,"

"Connectivity" and

"New services and ecosystems."

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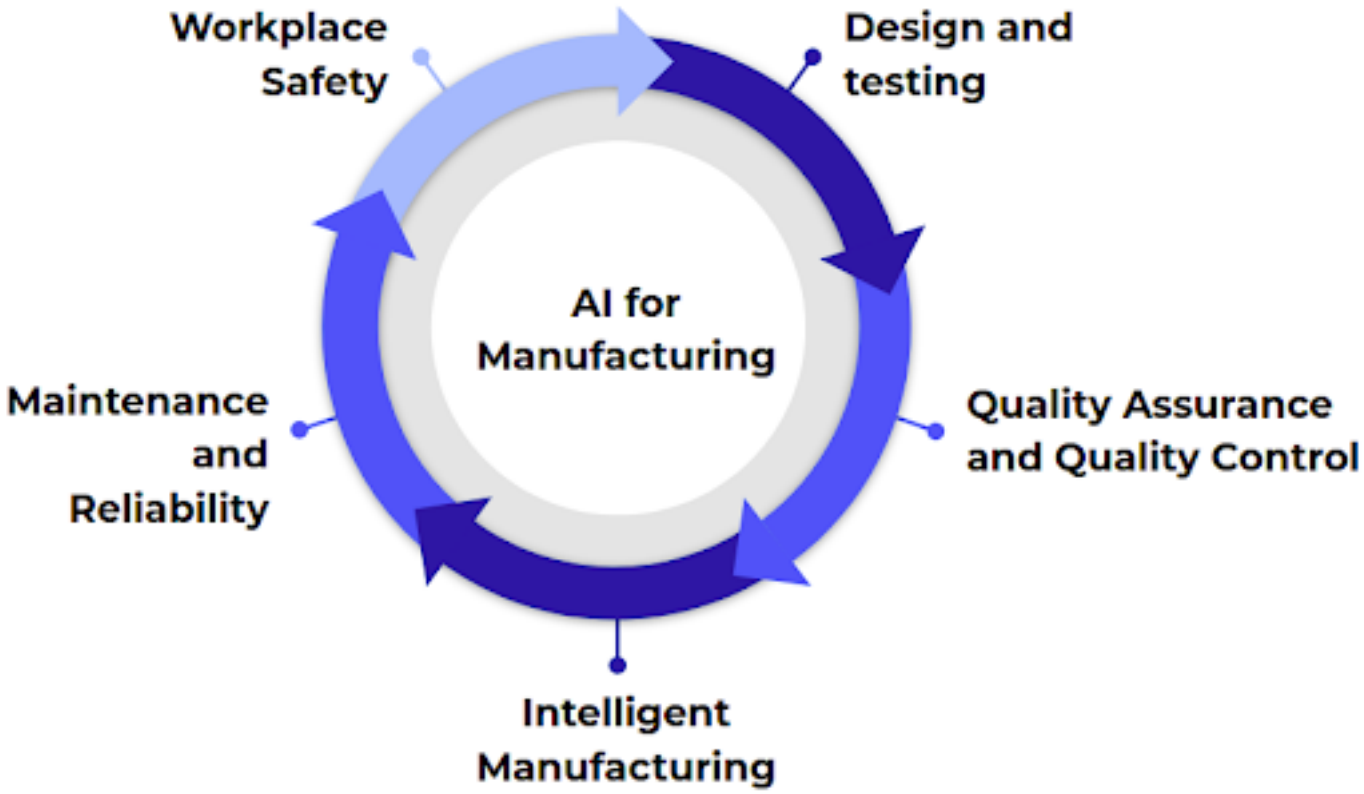


This reading material explores different ways AI can aid in the manufacturing process of a product. In manufacturing, AI aims to distinguish the problem during the production and help find the appropriate solution for that problem, as shown in the above figure. AI can be implemented in the Design and Testing of the product at the earlier stage of production, quality assurance and control, intelligent manufacturing maintenance and reliability, and workplace safety in a production environment.

4. Design and Testing

In the design phase for any product, we have to create a geometric model.

Geometric modeling is the study of methods and techniques for the mathematical descriptions of the object. So you need to represent a cuboid mathematically; for that, you will need the length, breadth, and height. You will need many parameters to define them for other complex models, like the curvature and many others.

In the modeling, we mostly use the three-dimensional object in our Computer Aided Design(-CAD) model. CAD is modeling software that engineers and designers use for modeling.

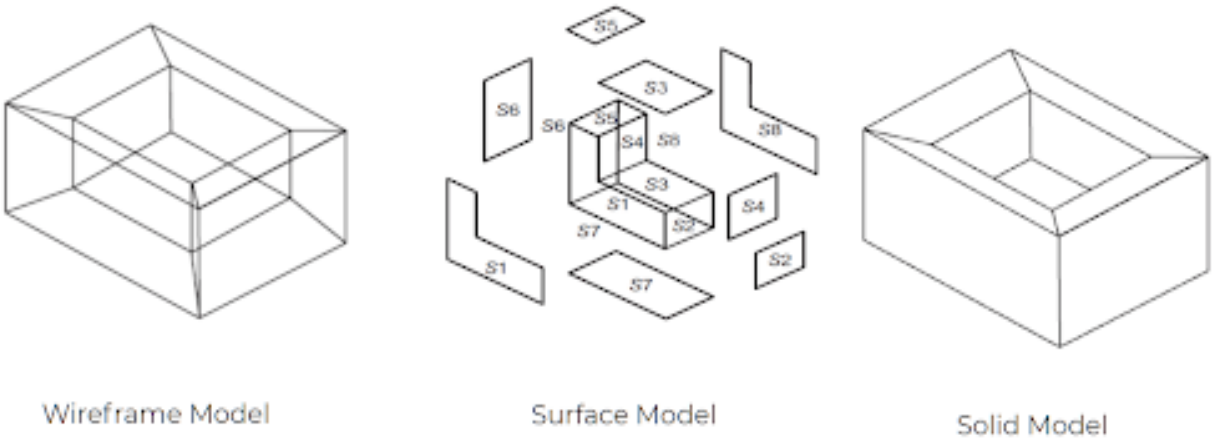


Figure 4: Types of Model

Generally, there are three types of modeling.

- **Line modeling or wireframe modeling**
  In this type of model, the object is represented by a bunch of lines connecting from verti ces to vertices. The line joining the vertices is called the edge.
- **Surface modeling**
  The surface model is a set of surfaces. These surfaces are also often called faces. The sur face model defines the geometry of the object.
- **Volume or solid modeling**
  The solid model is defined by the volume space contained within the defined boundary of the object. The solid model stores both the geometric and topological information.Here topology means the properties of an object preserved under continuous deformations like stretching, crumpling, twisting, and bending.

Designing anything ground up is quite a hectic and expensive task. AI is efficient in design and testing because it uses a technique called generative design.

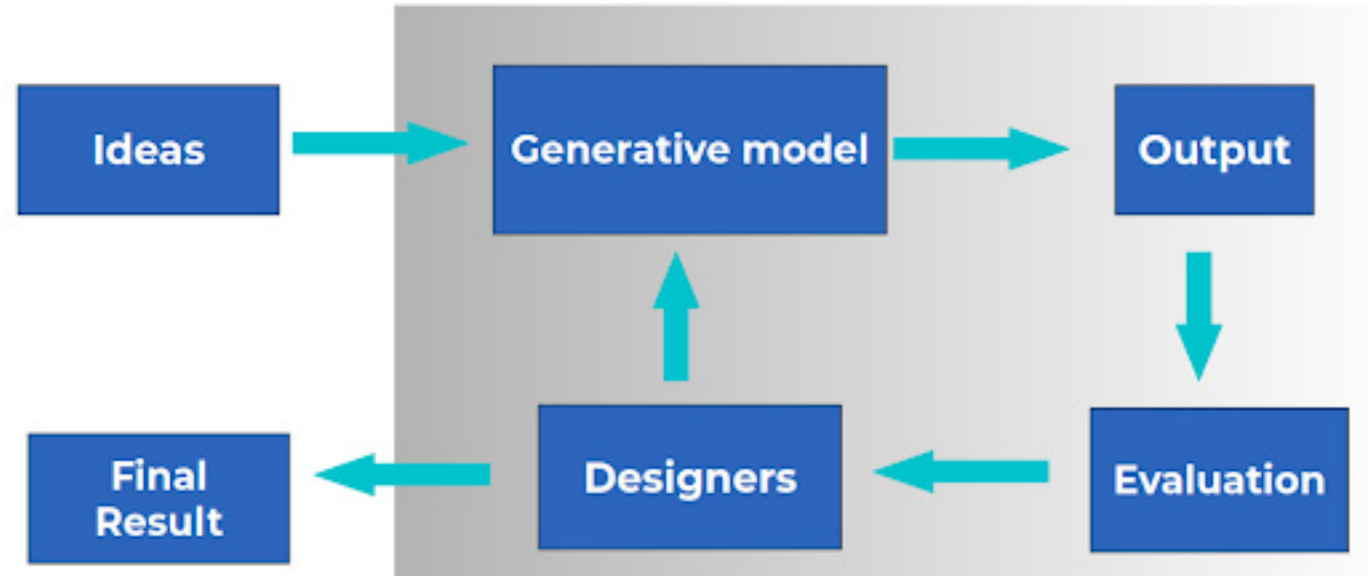


Figure 5: Generative Design

Firstly we have to have an idea about the product. We need to have parameters like product type, dimensions, weights, shape, etc. For the design pipeline, like any other design method, we have to know the product. We need to have parameters like dimensions, weights, shape, etc., and we feed the required parameters for the product to the generative model. The generative model is an AI model. The output from the model can be a 3d object, an image, and so on. It depends upon the need of an organization.

The output from the model is then subjected to the evaluation process. Modern generative design software is capable of carrying out the evaluation. For the evaluation, the model's solutions are tested for various factors like stress handling, strength on the different parts of the component, etc.

The generative design replicates the natural world's evolutionary approach. It means it provides several solutions(in thousands) to one problem. For example, if you need to design a chair, you will input the dimensions of your planned design and the parameters like expected cost of manufacturing, materials to be used, and so on. The model will output several solutions. You will choose the solution you think is the best, and again, you input the solution that you think is the best among the others into the model. And again, the model outputs the possible solution under the provided parameters. This is the evolutionary approach for generative modeling.

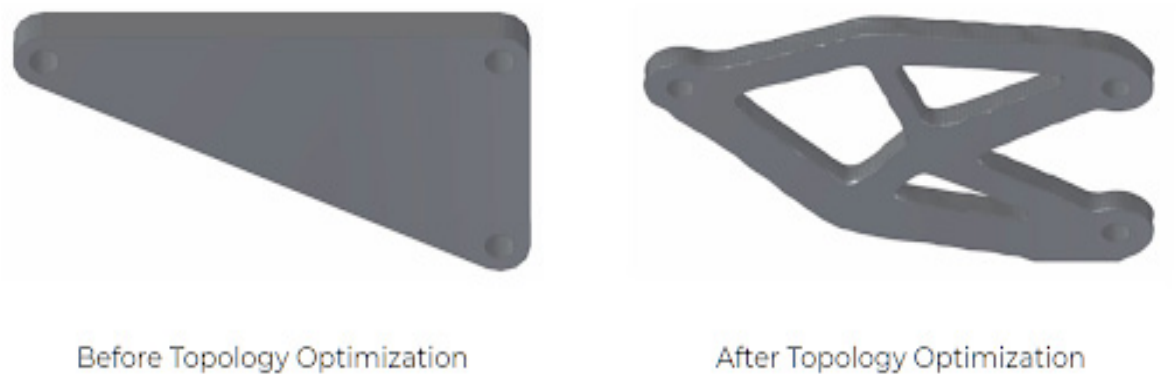


Figure 6: Topology optimization

Another aspect that we can work on for the product design is topology optimization. Topology optimization is the process of optimization of the material layout within a given design space. It is the act of deciding where to add the materials in the object so that we can make a strong yet light product.

In 2013, General Electric launched "GE jet engine bracket challenge" to design an engine bracket to fit in the jet engine. Here is the result of that challenge.

Figure: 7: GR jet engine bracket challenge(Left: sample model by GE, Right: Winning model)

5. Quality Assurance and Quality Control

Apart from producing goods, the manufacturing industry has to produce a quality product. To ensure that the manufacturing companies have to inspect them.

For a long time, it has been carried out by human agents. Quality control using the manual way includes humans as an inspecting agent. The items that come out of a production line has to go through the inspection of a human.

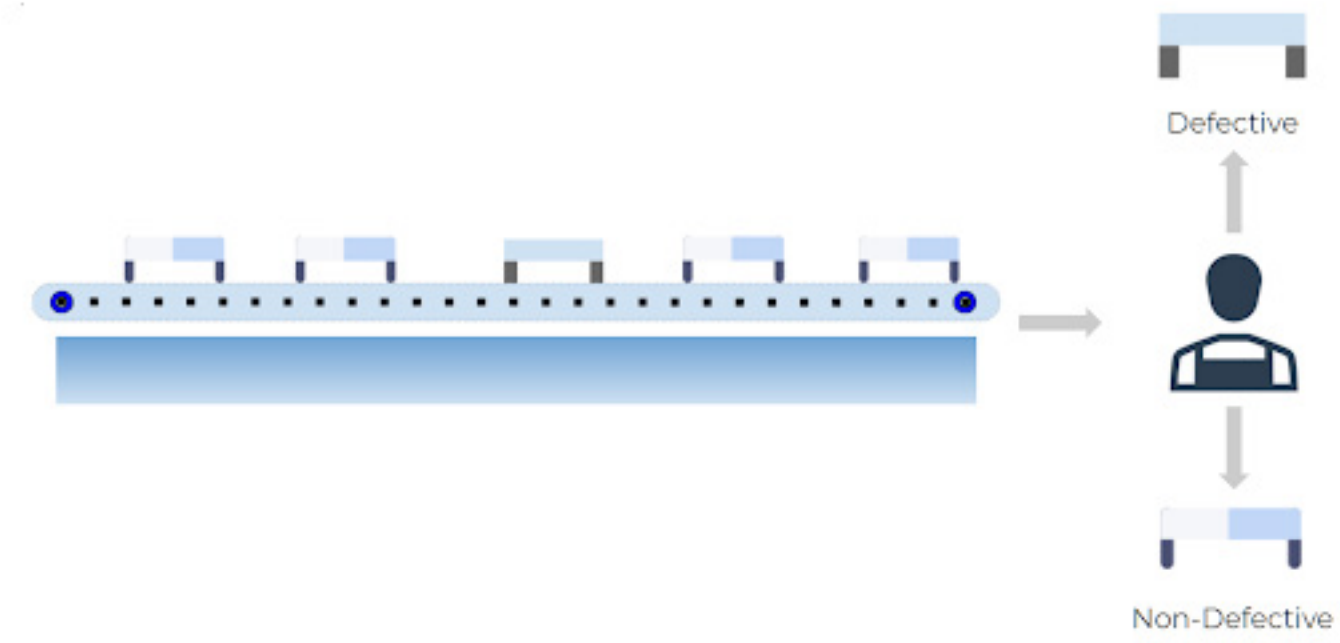


Figure 8: Quality Control by humans

Humans employed on the assembly line decide whether the product is satisfactory and ready for the market or reject the product. The manual method is a slow process. Humans take their time to inspect the products, which increases production time. In addition to that, humans have to be paid. The wages increase production costs.

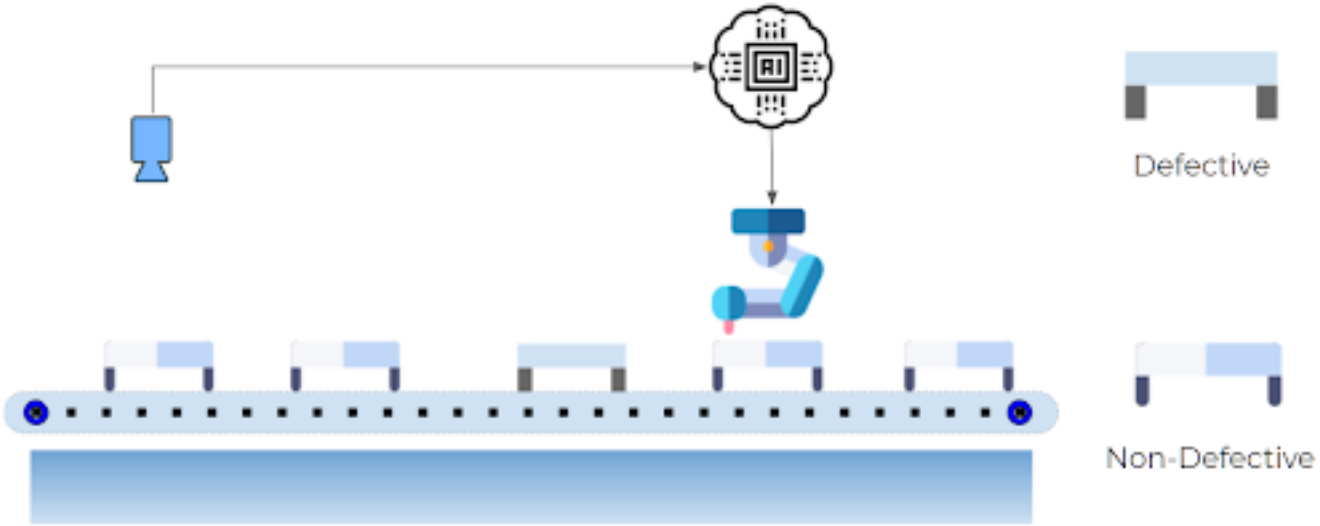
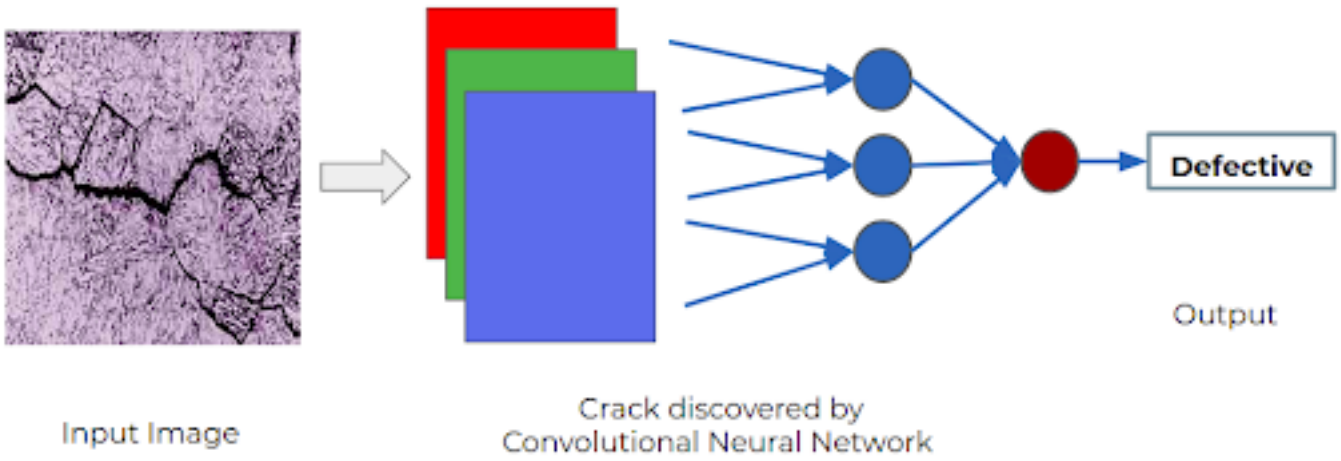


Figure 9: Automated Quality Control

In an automated assembly line, we replace the human player with the ai enabled system.
In the AI-enabled assembly line, first, the cameras capture the product's images from different angles.
The image data is then fed to the ai enabled system, where the ai system compares these images with the images of non-defective products.
The system is trained with plenty of past images captured by the cameras.
If the system detects any of the product's defects, then, The system triggers the robotic arm in the assembly line to sort out the defective product from the non-defective ones.
The expected benefits from such systems are improved quality of the products, decreased production time, and reduced cost of manufacturing.
One of the largest auto manufactures BMW has employed AI in its assembly line to detect the faults and cracks on the newly made components.

6. Intelligent Manufacturing

Intelligent manufacturing is the act of manufacturing the products in an optimum way. Which basically means producing more products using less of the resources. For this task we can schedule production time cleverly, select parameters for the productions and so forth.
One is production scheduling, For a schedule to be any good, it has to utilize the resource and yield maximum production.



If we wish to make AI schedule the task, we have to train it first like any other AI model. To train the model, the model requires historic data from the company's database, Here we assume that neural networks are used to train the scheduling model.

After the model learns from the historic data of the company, then the model gives bespoke schedules. This is the basic idea behind the scheduling using AI.

Another aspect of intelligent manufacturing is parameter selection.Consider we are in an iron sheet milling factory. To make maximum production by the minimum use of the resources, we need to make adjustments to a few of the factory parameters; these might cut the speed of the

machine, feed rate for the machine, number of workers needed at the stations, to name a few. The reason we need optimization of the parameters is that we need maximum production, obviously. We have to avoid the hazards in the productions like resource wastage, hold on to the production, and do not forget the defective products that the machine churns out in the lack of optimization.

An AI system can help with the hassle of parameter selection. The model takes the industry parameters as we discussed before to give us the parameters for smooth production.

Resources:

Microsoft's 2019 manufacturing trend report page 24-31

7. Maintenance and Reliability

We talked about improving productivity, designs and quality of products; which are essentials but let's not forget about the machines that produce them.

Health of the machines are on the frontline of the production. As we know, the health of machines declines with use. After a certain period, some maintenance is required to keep the machine working at its maximum potential.

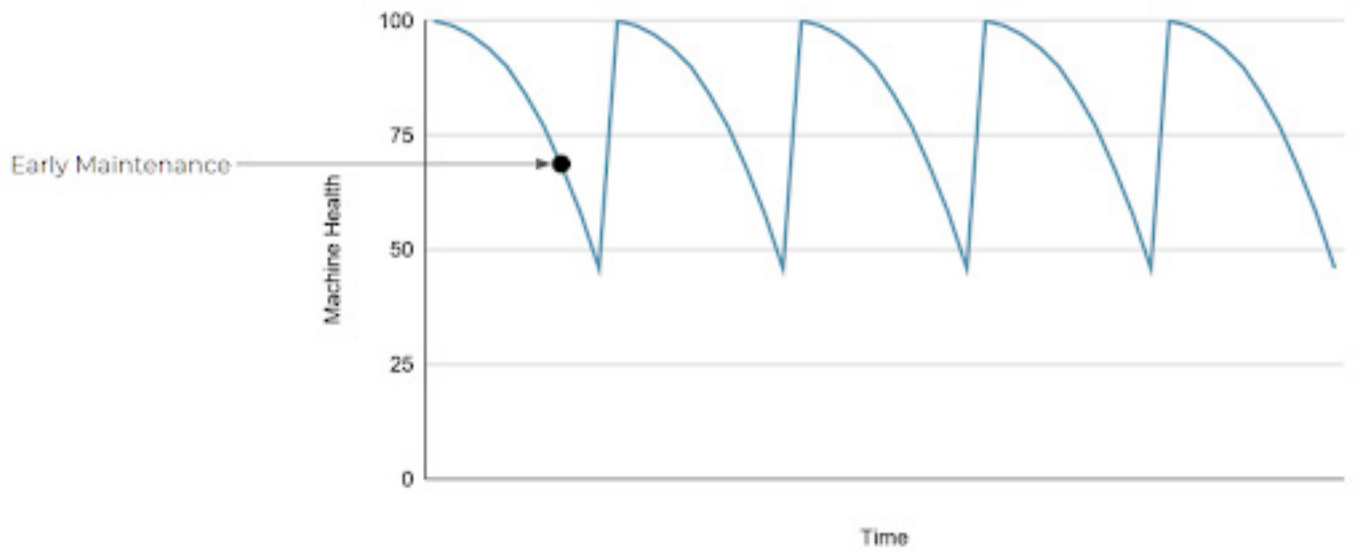


Figure 10: Machine health with predictive maintenance

It might be challenging to find that time window when maintenance is necessary. If we do the maintenance too early, we may waste the usable life of the machine. But if we go a long time without maintenance, the machine's health may decline severely, and the machine might not be in working condition without a major repair. In both conditions, the expense of the company increases, which may affect their profit.

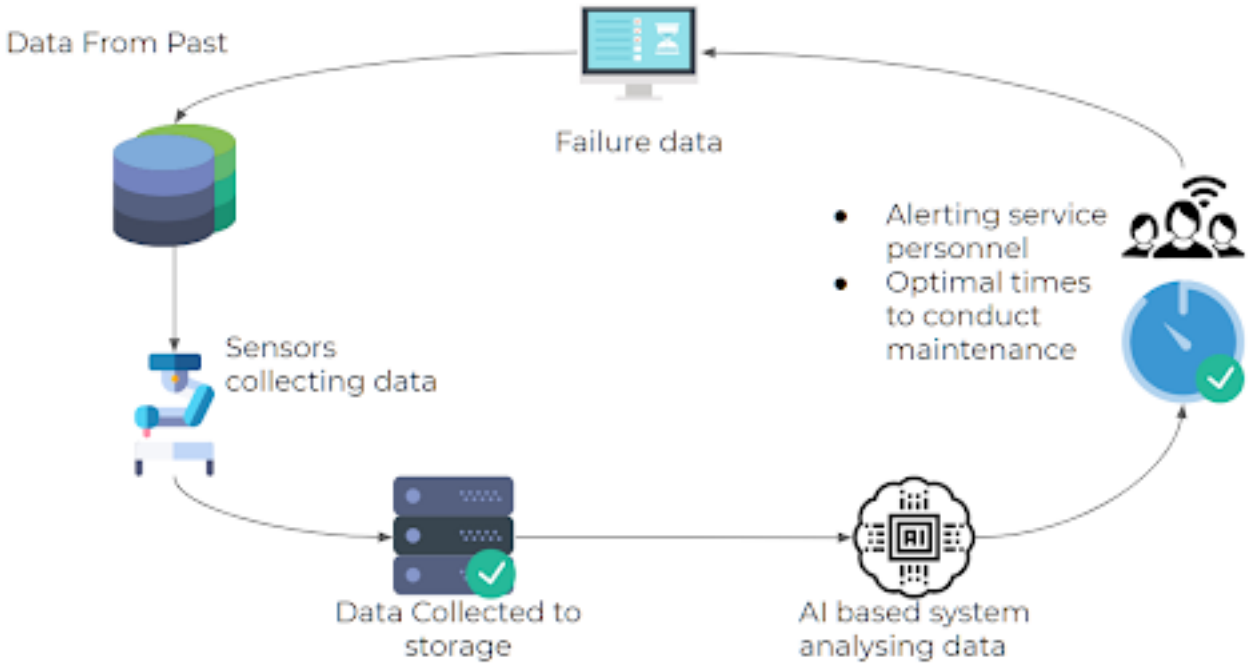


Figure 11: Implementing AI in predictive maintenance

The AI system that makes all the decisions is trained on historic data. All the machinery components failure data is used to train the model. Data on various operational parameters affecting the machine's performance is continuously collected from the sensors that are fitted to the machine components. The collected data is then stored to the data storage. Then the AI based system analyses the data. If the AI system detects any fault in the system then, It alerts the related personnel for the possible action. And also we can make the AI system to predict the optimal time to conduct the maintenance of the machines.Newly acquired machine failure data is again used as a training dataset for the AI based system. And the cycle continues.

Now, what are the benefits of it?
We will certainly have low maintenance costs, we will have less cases of equipment failures meaning we will have high Overall Equipment Effectiveness(OEE). And we do not have to halt the production unexpectedly.

General Motors has implemented a similar system into their manufacturing facility.
The system they implemented analyzes images from cameras mounted on assembly robots, to spot signs and indications of failing robotic components with the help of its supplier. In a pilot test of the system, it detected 72 instances of component failure across 7,000 robots, identifying the problem before it could result in unplanned outages. According to the Robotic Industries Association, the cost of just one minute of production-line downtime for a company like General Motors can be as high as $20,000.

8. Workplace Safety

Producing the goods is the priority for any manufacturer. But for the running of those factories, the safety of the workers are also essential. To ensure the safety of the workers, companies like Microsoft have developed systems for the task.

The system works in the following steps

i. Surveillance cameras capture images
ii. Analyze possible hazards
iii. Inform related personnel
iv. Take necessary actions

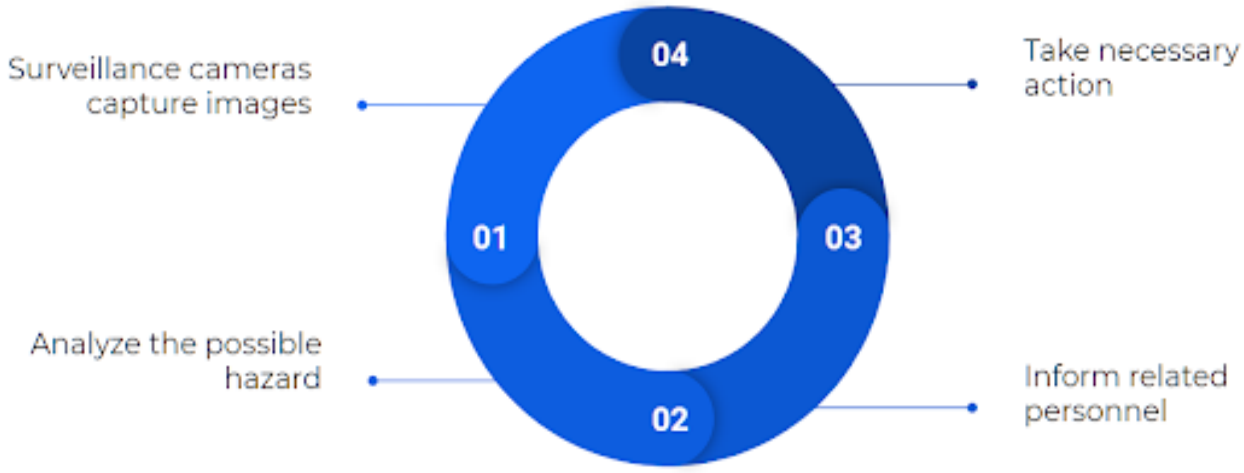


Figure 12: Workplace Safety steps

Firstly, the surveillance cameras fitted into the several stations capture images and feed them to the AI model. The model analyzes the possible hazard. If the AI model detects any possible hazard, it immediately informs the related personnel through their phone. And the authorized personnel take necessary action.

The context in this picture is of a chemical factory. This system that they developed alerts the responsible personnel for the possible hazard. The surveillance camera takes the image. The system detects the spillage of the chemicals or any other type of anomaly on the factory, storage, or any other place and analyzes the possible hazard.

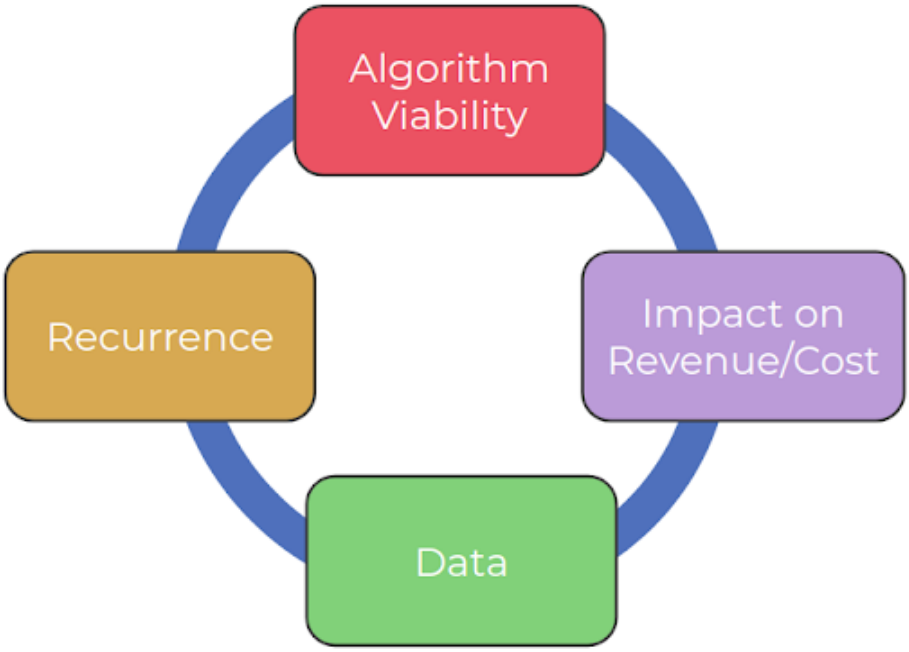
9. AI in Energy Sector

In the present time, AI has found itself essential in energy sectors too. For example, a Texas-based startup named "Innowatts" has developed an automated toolkit for energy monitoring and management. The company's utility platform ingests data from more than 34 million smart energy meters across 21 million customers, including major U.S. utility companies such as Arizona Public Service Electric, Portland General Electric, Avangrid, Gexa Energy, WGL, and Mega Energy. Innowatts says its machine learning algorithms can analyze the data to forecast several critical data points, including short- and long-term loads, variances, weather sensitivity, and more.

In 2017 google collaborated with IBM. Using the DeepMind Ai platform of IBM, Google developed an ML algorithm to boost 700 megawatts of wind power capacity in the central US.
According to IBM, by using a neural network trained on widely available weather forecasts and historical turbine data, DeepMind can now predict wind power output 36 hours ahead of actual generation.

The product produced by Korean startup "Alchera" uses AI-based image recognition combined with thermal and standard cameras to monitor power lines and substations in real-time. The AI system is trained to watch the infrastructure for any abnormal events such as falling trees, smoke, fire, and even intruders.

10. AIDR Framework



- **Algorithm Viability:**

Suppose you want to build a system that detects faults in the machines' mechanical components in a factory. Also, the system is capable of repairing the faults in the machine.
Then that's probably a little far-fetched, based on the state of the art research.
But suppose you want to build a system that can predict when the machine needs maintenance by analyzing the data from the sensors fitted to that machine. It would also be possible for the system to track the health of those machines.
In that case, it's probably likely that you will be successful rather than having a system capable of mending the failures in its mechanical components. It's probably a little far away.
You need to be aware of the research that is happening daily or weekly where you know most of the art algorithms' state.
Say you want to make an AI system to predict time before maintenance. For this, you will need a regression algorithm. It is because you are looking for the days before maintenance.

You can use several regression algorithms like linear regression, support vector machine regression, or also you can use neural networks. It all depends on the type of data you are using and the order of precision you are expecting.

- **Impact on Revenue/Cost:**

Another thing you need to understand or you need to think about is the impact on the business world by the AI system you build. With the plan like, whether the system saves more money or not? Or is it going to increase the revenue for the business and so forth? For example, a quality inspection system that sorts out defective products.

So, one needs to think hard about how it impacts the ROI of the business or the key metrics of the businesses, as it increases sales or saves costs. So, this is all that the term I for impact and revenue cost is all about.

- **Data:**

There are several things to plan when you think about data for building AI models. First, is, how much data? Many new algorithms, such as deep learning systems, are being built and shown to be useful across many different problems.

We have to consider ways of acquiring data. We can fit the sensors to the components and collect data from there, or we can outsource it.

And also, AI does require a lot of data. So, we have to collect a massive amount of data. Is it useful data? We need to have data that are relevant to the problem we are trying to solve.

We also need to think about the system capability of training itself after implementing from the data provided by the sensors. We can make this type of system according to our needs.

- **Recurrence:**

There are a lot of things that we do daily, weekly, monthly, yearly. One of the core powers of AI-based automation is that it allows you to free up the time from all these repetitive tasks that you have to do daily or weekly. Suppose you need to automate the task of checking your machine's health daily or weekly. That becomes very powerful because that allows the system to do something daily and weekly, which means it will start freeing up a lot of your time to do other things.

11. Challenges of implementing AI in Manufacturing

Challenges of implementing AI in manufacturing means the factors that are hindering the wide applications of AI. There are several factors affecting the implementation of AI in manufacturing.

- **Legacy machinery:**

Legacy machinery is already present in the production plant. The problem with the legacy machines is that whenever a "Cool and Revolutionary" technology emerges, it is not always easy to integrate these new systems into existing machinery types. Vendors offer a wide range of components to adopt the technologies; compatibility becomes a headache for the operators.

- **Inability to access and leverage data:**

Commonly the production line in any industry is noisy, vibrating, dusty, and the ambient temperature fluctuates quite regularly. These conditions may lead to inaccurate data collection. and also, if the industry is in a remote location, then it adds complexity to the computerized system.

- **Demand for real-time response**

In Industry 4.0, the monitoring of every component of manufacturing is essential. Several applications in manufacturing are sensitive to latency, such as predictive maintenance. Such applications require a fast response. For this type of application, making a round trip journey to the cloud to get the decision is inappropriate. Hence this type of computing requires edge computing. Where the data processing and other tasks are carried out on edge devices such as machines themself, local gateway or local server.

- **Lack of AI talents:**

Most of the technical personnel working in the industry are not trained in building a system equipped with AI. Also, there are just not enough AI engineers, AI strategists, and AI consultants out there who could help with a lot of these initiatives within large organizations. But, many organizations are starting to think through how to retrain their workforce on AI, how to hire more AI engineers, and so forth.

- **Trust against AI:**

The thing is that, in the manufacturing industry, the prediction model's reliability is critical, And high accuracy from the model is expected. There might be a condition that the model can be fooled by exploiting the faults in the model. In addition to that, we have a firm belief that the work done by human is always reliable which also helps in our biases against AI.