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HOW INDUSTRIAL ANALYTICS BACKED BY IOT WILL TRANSFORM MANUFACTURING INDUSTRY:

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ABSTRACT

In the present scenario of Industry 4.0, a large volume of data is being generated everyday in the manufacturing industry. The large equipment that operating in the industry are generating huge data daily. Industrial Analytics (IA) tackles the collection of data that is created during manufacturing process and analysis of that data to find and capture unique patterns that can increase the productivity and help the company towards effective decision making. Industrial Analytics need IoT sensors to work effectively and these sensors are responsible for capturing the data required for the analysis and finding out unique patterns. Industrial Analytics based on IoT will not only improve the whole process of manufacturing, it will also increase the overall efficiency and productivity, better quality assurance and also improve the workers' safety. Industrial Analytics based on IoT is being extensively used for the purpose of Predictive maintenance of the large industrial equipment/machines. This research discusses the process of how Industrial Analytics is being used for the purpose of predictive maintenance, related types and workflows, current market growth and future, limitations of predictive maintenance. The paper also discusses few cases where industrial analytics was successfully implemented.

1. Introduction

Predictive maintenance has quickly emerged as a leading Industrial Analytics use case for manufacturers and asset managers. (A Study by Markets and Markets [1] forecasts the global predictive maintenance market size to grow from USD 3.0 billion in 2019 to USD 10.7 billion by 2024, at a Compound Annual Growth Rate (CAGR) of 28.8% during the forecast period). Predictive Maintenance is one of the most widely used applications of Industrial Analytics. Predictive Maintenance requires extensive use of IoT sensors to collect the huge volumes of data generated by the large Industrial equipment. (McKinsey Global Institute [2] has also predicted that IoT will reach a few trillion dollars in the next decade. The emergence of IoT is going to be the main driving force for Predictive maintenance.

Now the question arises what is Predictive Maintenance? Predictive maintenance evaluates or examines the condition of large industrial equipments/machines by continuous monitoring with the help of IoT sensors and with the help of analytics we can find the patterns or under which conditions particular equipment can get damaged or stops working. The downtime of these types of equipments can cause huge losses to the organization and the whole business process is hampered. Predictive Maintenance can help uncover important data regarding these types of equipments and help the company predict when particular equipment/machine is going to stop working. Predictive maintenance helps manufacturers to reduce the cost of maintenance, improve machine life and improve production quality by evaluating machine's condition before they cause equipment failures. Predictive maintenance can become a very important part of the Business continuity plan. (In fact, a joint study by Wall Street Journal and Emerson [3] found that unplanned downtime costs industrial manufacturers an estimated $50 Billion per year. Equipment failure is the cause of 42% of this unplanned downtime).

2. Objective of the paper:

The systems that are used at present in many factories have limited capability in view of the analysis and storage of historic data. The manufacturing organizations have started to realize the benefits of adopting predictive maintenance strategy and hence they have started to spend big to improve their production quality and efficiency. This paper discusses how the whole process of predictive maintenance takes place and what are its advantages over traditional maintenance approaches? The paper also discusses about the different types of predictive maintenance, the current situation of the predictive maintenance market and the limitations, and what the future of Industrial Analytics is in the coming days. This research paper also discusses two industry use cases where predictive maintenance approach was successfully implemented.

3. Literature Review:

Machines and equipments are constantly in operation in manufacturing organizations. Considering the huge competition in manufacturing industry, no single organization wants to compromise on production hours but every machine is prone to wear and tear and at some point is going to fail. Companies have previously lost huge amounts of money due to unplanned outage which resulted in reduced productivity and efficiency. Unscheduled downtime can scale up to 500 hours per year in an organization which leads to overall costs in the range of $20,000 to $30,000 per hour [4]. Predictive maintenance can solve this problem by predicting the failures beforehand and also helps identifying where the fault has taken place. This reduces the cost of maintenance and at the same time the productivity and efficiency is also not disturbed. In addition to acting before failure, even if there is no immediate danger predictive maintenance aims to attend any fault predictions to ensure that the that the daily operations take place smoothly and excess energy is not consumed [5]. Predictive maintenance is adopted by many industries not just manufacturing organizations but also other service industries to improve reliability, availability, quality, efficiency and safety. The faults in machines are predicted by the help of IoT sensors. The IoT sensors are hooked to the machines to collect and consolidate the data to be then put on cloud platforms where analysis is done using advanced statistical techniques. This internetworking and connectivity in the shop floor can help manufacturers capture important patterns about the machine's health and performance. IoT has enabled manufacturing organization to monitor the machine's activities and controlling them which enables organizations to plan maintenance activities in a much more efficient way [6].

According to the study conducted by ABB US Corporate Research Center, ABB being a global power and Automation technology company collects huge volumes of industrial data from the power systems and uses that data to analyze their systems efficiently. ABB has conducted initial predictive machine learning experiments by using data generated from power systems and public weather data to forecast fault events [7]. The data that is generated by the IoT sensors from the machines are used to develop a model which can predict the faults in machines. Various algorithms in machine learning space like logistic / linear regression and advanced statistical approaches like neural networks are used to develop the model. As posited by Silvestrin, Hoogendoorn and Koole [8], the deep learning approaches that are able to extract the features automatically have been utilized (including LSTMs and Convolutional Neural Networks), showing promising results in the field of predictive maintenance. Such statistical approaches make it possible to monitor real time data from sensors and make predictions which help analysts take better decisions in terms of maintenance.

4. Research methodology:

This research aims at certain case studies on the topic. Initially the types of maintenances – like preventive, reactive and predictive – are described to provide the background and then the individual cases are narrated. When dealing with maintenance of machines and equipments in the manufacturing organization, there are broadly three maintenance strategies that are being adopted worldwide. When we are considering low priority equipments the Reactive maintenance approach is accepted worldwide. Reactive maintenance is the type of maintenance strategy in which the machine is used to its limits and once the machine fails then repair is done. Such maintenance strategy can be used for low priority machines like bulbs where the cost of repair is low and less staff is required to repair. But when dealing with large equipments such a maintenance strategy will not work as a machine downtime can cost the organizations millions of dollar along with high cost of repair and labor cost. The figure 1 shows how reactive maintenance works.

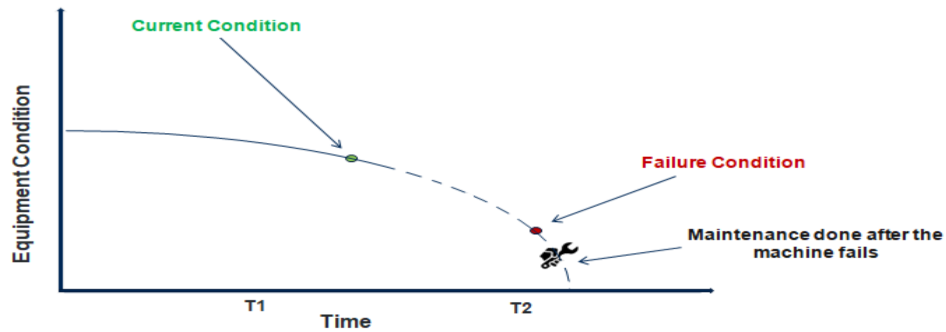

Figure 1: Reactive Maintenance [9]

Previously to avoid machines from failing Preventive maintenance approach was adopted. In the Preventive maintenance strategy, manufacturers perform regular maintenance activities with the aim to prevent the breaking of equipment and hence the maintenance tasks are planned at set intervals as per equipment-specific needs to repair or substitute the critical components. The main drawback of this approach is that maintenance is often issued at times when it is not needed. Hence the cost is also high due to regular maintenance and the machine life is not completely utilized. The figure 2 shows how preventive maintenance works.

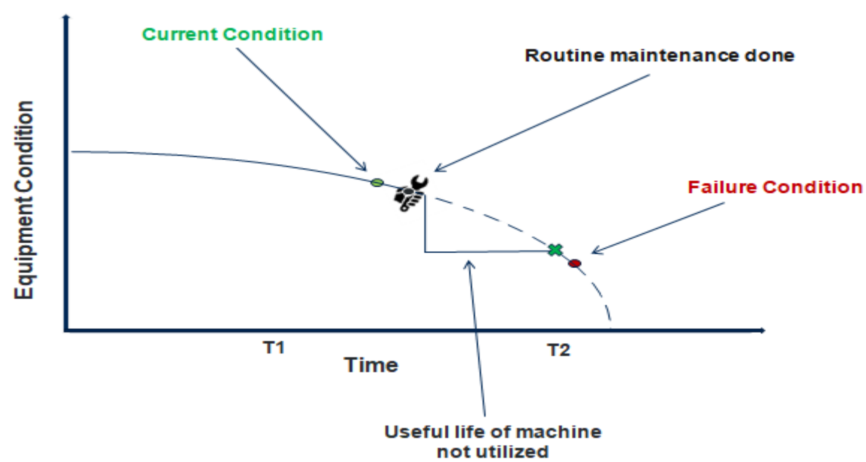

Figure 2: Preventive Maintenance [9]

After the introduction of analytics and IoT technologies the preventive maintenance approach is getting outdated. If organizations can predict faults or machine downtime then the maintenance is not needed all the time it can be scheduled just before the machine fails. Such a maintenance strategy is called Predictive maintenance, a type of maintenance that examines the status of large industrial equipment/machines by continuous monitoring with the help of IoT sensors and with the help of analytics we can find the pattern or under which

conditions particular equipment can get damaged or stops working. The figure 3 shows how predictive maintenance works.
(A Study by Markets and Markets [3] forecasts the global predictive maintenance market size to grow from USD 3.0 billion in 2019 to USD 10.7 billion by 2024, at a Compound Annual Growth Rate (CAGR) of 28.8% during the forecast period)

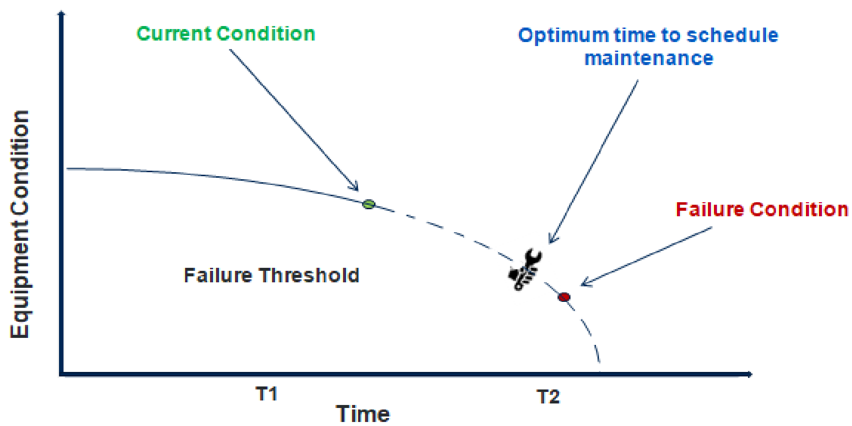

Figure 3: Predictive Maintenance [9]

Predictive Maintenance is one of the most widely used applications of Industrial Analytics. Predictive Maintenance requires extensive use of IoT sensors to collect the huge volumes of data generated by the large Industrial equipments and considering the fact that McKinsey Global Institute predicts IoT will generate up to $11T for the global economy by 2025 which clearly indicates the predictive maintenance market is going improve a lot in the coming days.

5. Predictive Maintenance workflow:

In order to understand the complete workflow we will take the case of a Triplex pump which is extensively used in the Oil and Gas industries. A triplex pump is very important equipment and proper maintenance of this equipment is necessary to avoid disruption in production plans. The objective here is to predict the fault so that the maintenance can be scheduled beforehand and productivity issues can be avoided. Our objective here is to detect anomalies, classify different kinds of faults and estimate the remaining useful life (RUL) of the machine (Triplex pump). In order to develop a proper model which can predict equipment failures following steps need to be taken. The steps for successful implementation of predictive maintenance are shown below in figure 4.

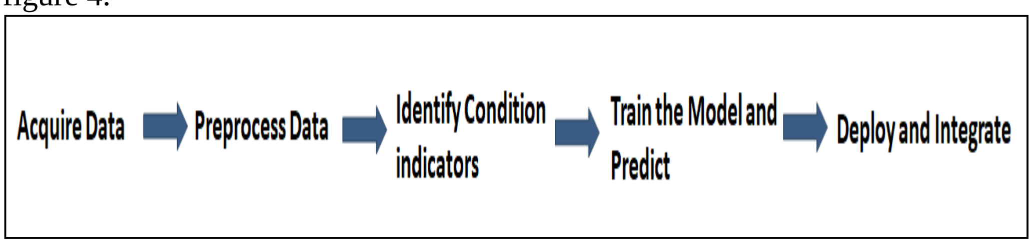

Figure4. Predictive Maintenance Workflow [9]

We can see from the above diagram that there are 5 steps which needed to be taken care of to implement predictive maintenance in a manufacturing organization. Let's look at each step and understand its significance:

a. Acquire data: The first step of the implementation process is acquiring data. In order to collect data, sensors are attached to the pump and the sensor continuously collects data when the pump is operating. It is important that we collect data of not only one pump, it is important that we collect data for other pumps working under different conditions so that we can develop a robust model which can predict failures irrespective of the operating conditions. In the case of the Triplex some important parameters like Temperature, pressure, viscosity of the fluid are collected as data along with the equipment's operating patterns.

b. Preprocess data: After the step of data collection it is important to process data before we start analyze it. Sometimes there may be cases where the sensor is not able to collect much data which can help in prediction in such cases we develop a mathematical model of the pump and try to generate fault data by making the pump operate under different conditions. The synthetic data generated is now combined with the sensor data so that we have all the parameters in place for analysis. During the process of preprocessing it is important we remove outliers so that we can reduce the variability of data and improve the predictions

c. Identify Condition indicators: This is the most important step in the whole process which is identifying the condition indicators. In this step we will try to identify those conditions where the machine fails to operate. This is the step where we try to find out anomalies and the values of the parameters which trigger the faults in the equipments.

d. Train Model: After identifying the values of the parameters which results in equipment failures the data is then fed to the model and by the help of machine learning algorithms and other sophisticated techniques like neural networks we try to predict the faults and which part of the pump is going to fail. We identify trend lines so that we can calculate the remaining useful life (RUL).

e. Deploy and Integrate: After developing the model we upload the model on cloud or on your edge device. The IoT sensors connected to the pump continuously generate the data which get uploaded on the cloud and predictions are done on cloud or your device and when any deviations are detected the concerned authority is alarmed beforehand. The advantage of deploying the model on cloud is that the organization can then integrate the data from different business units and predictive maintenance can be deployed on a larger scale. The operators can continuously examine the equipment's operation every time on their device by connecting to the cloud. [9]

These are the basic steps that are required to implement predictive maintenance. A simplified model of predictive maintenance is shown in figure 5.

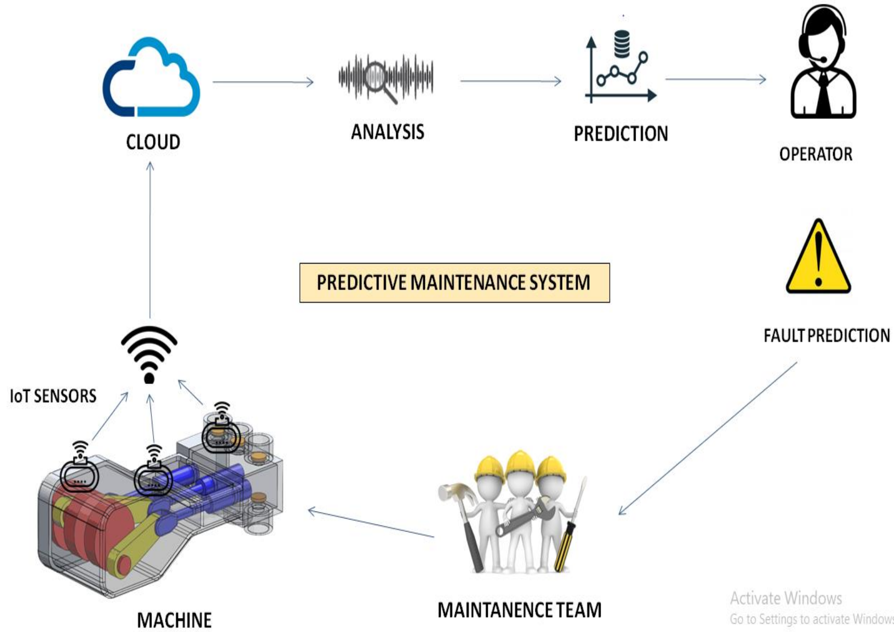

Figure 5: A Simplified model of a predictive maintenance system [10] - [15]

We can see from the above diagram how a predictive maintenance system can predict faults which helps organizations better maintain their machines by scheduling maintenance just before the machine fails. Now let's dive deeper into the analysis and prediction part and see how analytics is improving the whole system.

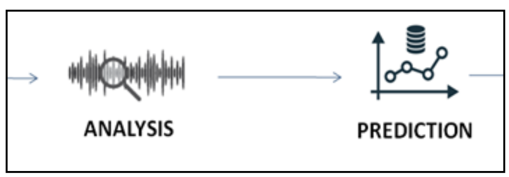

Figure 6: Analysis and Prediction

From the early 2000s, sensors were used by the manufacturing organizations to predict machine's downtime by the use of alarms. From the historical data collected from the sensors a threshold value was determined for triggering alarms. The sensors collected the data from the machines and when the numbers increased a predetermined value, alarm was triggered to notify the authority about the machine's condition. But alarms had low accuracy because there were cases where the data collected by the sensors was below the threshold value but still the machine failed. This is where analytics or machine learning algorithm improved the efficiency the predictive maintenance system. The figure 7 given below, shows how alarms were triggered when only sensors were used.

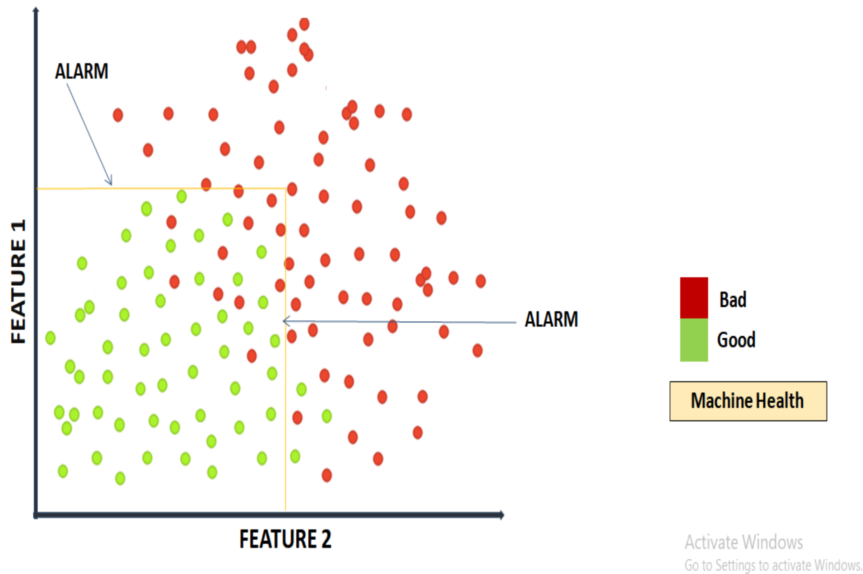

Figure 7: Alarm systems before using Analytics [16]

From the above figure given we can see that data from two sensors that is values of Feature 1 and Feature 2 were plotted on a two dimensional graph. When analysts used only the sensor data they could only determine threshold value after which alarm was triggered for machine failure. From the historical values of sensor data they could determine the machine's health but failed to draw a boundary in real time as it is difficult for human mind to continuously study such huge volumes of data and interpret the relationships between different sensors simultaneously. We can see in figure6 the values below the lines have a number of cases where machine health was bad (denoted by red dots) but alarm was not triggered. Such cases can cost the organizations and also disrupt the production plans when the machine fails to operate but alarm was not triggered.

Now let's take a look how analytics or machine learning algorithms along with sensor data better predict the fault as well as better determine the machine health. Machine learning algorithms and advanced statistical techniques can draw complex boundaries which helped manufacturers determine machine health more accurately. The given figure 8 below shows how analytics and IoT together can improve the predictive maintenance approach. Here when the data from machines were captured by the sensors and analysis was done using statistical techniques, we can see how the model could determine the machine heath more accurately and also alarms were triggered with higher efficiency. Whenever new data is generated from the machines, the model could very easily determine the machine's health by accurate boundaries the model created. With more and more data the accuracy of the model will also improve. The maintenance can now be scheduled with higher accuracy depending upon the machine's health and production plans.

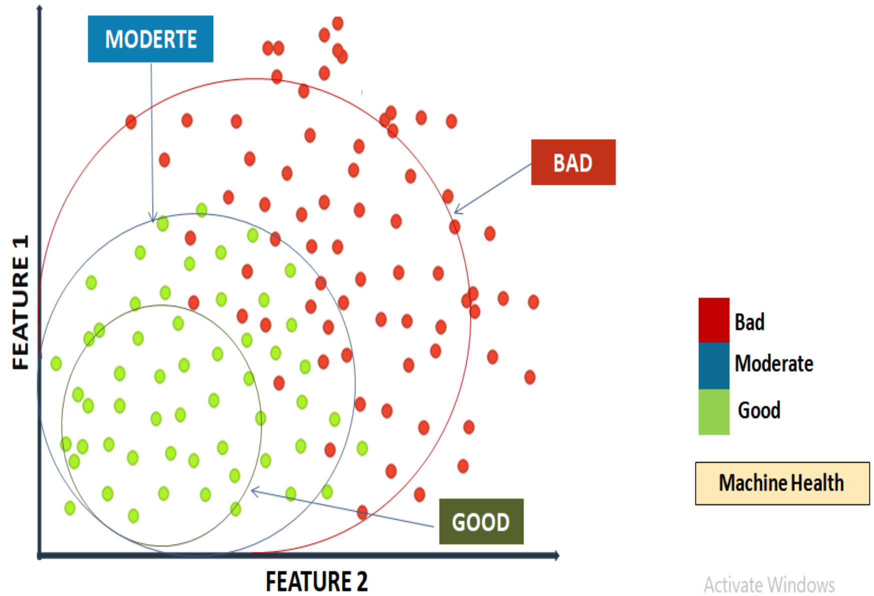

Figure 8: Alarm system after using Analytics [16]

Another advantage of analytics is determining the Remaining useful life (RUL). Based on the data generated by the sensors during the machine's operations, the model can predict the trendline helps the organization predict the fault. This helps organization to schedule the maintenance right before the machine fails so that the machine life can be better utilized and also production plans are not much disrupted.

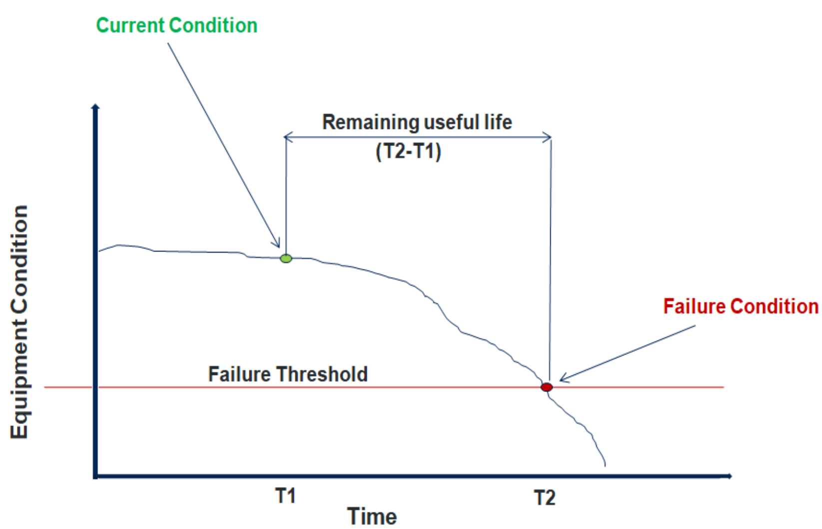

Figure 9: Remaining useful life (RUL)

The figure 9 above shows how the remaining useful life is calculated from the trendline predicted by the model.

Traditionally predictive maintenance was done by the floor managers using the SCADA system which is a computer system that gathered real time data from sensors and analyzed the data based on thresholds, alarms, and configurations set by humans. SCADA fails to explain what is going right or wrong in a process and only concentrates on control and what's not supposed to happen.

After the machine learning algorithms are used to develop a model which monitored the real time data generated from the sensors, accuracy of predictions also increased by a considerable margin (figure 8 and figure 9) and machine's condition is also better evaluated.

6. Types of Predictive Maintenance:

There are different types of equipments and machines that are currently working in the manufacturing organizations. The main goal of predictive maintenance is to predict machine failure and schedule maintenance based on the Remaining useful life (RUL). The manufacturing organizations are working with different types of machines so our analysis will also be different for every machine. The parameters or features that help us find the pattern in machine's operation will vary a lot when we deal with different machines. We need to collect data which will be used. There are mainly 3 types of predictive maintenance that are being used in the manufacturing organizations. The details of each type are given as follows:

a. Vibration Analysis: Vibration analysis is one of the most powerful techniques for predicting faults in machines. Typical machines for which vibration analysis is done are include motors, pumps, fans, gear boxes, compressors, turbines, conveyors, rollers, engines, and machine tools that have rotational elements. These machines having rotating elements which generates vibrations at particular frequencies during the operations. The amplitude of the vibrations indicates the performance and quality of the machines. The IoT sensors connected to the machine captures the vibration signals. The signal is converted into digital form for further analysis by signal processing algorithms like Fast Fourier transform, Time waveform analysis, signal filtering etc are used to extract data for understanding the performance and identifying faults [17].

b. Infrared Analysis: The infrared analysis is another powerful technique to understand the machine's conditions. Typical machines for which infrared analysis are done are mostly electrical equipments. The internal heat of the equipments may increase due to many reasons like unbalance loadings, contact problems, cracks in insulation which can lead to unplanned failures and can risky in terms of safety of workers. The advancement of new technologies helps us detect thermal abnormalities and by the help of advanced analytics we can predict the fault and also determine a timeframe for scheduling maintenance for particular equipment. Currently in many companies, speedy, dependable, non-contact and reasonably cost competitive infrared thermographic inspection systems are being used to detect the temperature variations in the equipments and take appropriate decisions [18].

c. Acoustical Analysis: Acoustical analysis is of two types one is sonic and other is ultrasonic. It is similar to the vibration analysis technique but acoustic analysis is mostly used to detect frictions in electrical and mechanical equipments, leakages in systems, and stress in rotator machines. Sensors can capture both ultrasonic and sonic sounds and helps professional capture patterns which help them predict equipment's condition [19]. Around 40 percent of the energy cost is due to air leaks and air leaks can cause significant decrease in machine's efficiency. It is also a cause for stress on machines which leads to failures. Acoustic analysis is not very much widely used compared to the vibration and infrared analysis but acoustic analysis is very essential due to distinct features this analysis provides.

d. Oil Analysis: Oil analysis is done by collecting data about the lubricant's properties and contaminations by the sensor connected to the oil pumps. We all know lubricants are lifeblood of machines and oil analysis helps manufacturing organization learn a lot about the machine's health which enable analyst to take informed decision about maintenance.

These are broadly the predictive maintenance techniques that are widely used in the industry. The advancement of IoT sensors have made it possible to collect data easily from each of these techniques mentioned. It is very important that the right analysis is done to collect good amount of data. The foundation of predictive maintenance depends upon the quality of data collected. Hence it is very important that while identifying the high priority machines for maintenance it is also important to do the right analysis on them based on the machine's properties which will lead to capturing of good quality of data and therefore better fault predictions.

7. Companies At Action:

Let's see some industry case studies where predictive maintenance improved their productivity, efficiency and also helped in reducing the cost of maintenance by considerable margin.

Case Study: Santos Ltd

- Company Overview: Santos Ltd. is one of the leading oil and gas producers in the Asia-Pacific region, serving the energy needs of homes, businesses and major industries across Australia and Asia. Santos reports annual revenues of AUD 4 billion (USD 2.9 billion).
- Problem statement: Santos operates one of the largest exploration and production businesses in Australia. The company's operations heavily depend on large and highly complex network of assets including thousands of pipes, wells, pumps, compressors and other equipments. One of the key priorities for the organization is to keep this network of assets continuously up and running as any downtime can disrupt production plans and reduce profitability. The company has connected all the equipments with IoT sensor and data is continuously collected and analysis is done by the Traditional SCADA Systems which is not much efficient in terms of recognizing the patterns and predicting the probability of fault. The company was suffering huge losses due to maintenance of this infrastructure as SCADA systems are not efficient in terms of fault predictions.
- Solution: To develop an effective alarm system for failures, the company used analytics to analyze the sensor data which enabled real time analysis of the operational data from sensors and the analysis is done at a speed at which the machines are operating by the help of IBM SPSS Lab services. This helped company gain competitive advantage in the market. Previously they only used between 10 and 12 percent of the operational data collected, which is the industry average and now the company could use almost all the data generated

and analyze the patterns and the predictions for machine failure also became more effective and efficient.

• Benefits: The Company has a potential annual saving of more than 10 million Australian dollars by increasing the production time. Santos Ltd was able to streamline their operations and was able to reduce the cost of maintenance by a huge margin by better maintenance scheduling. They were also able to improve the safety of the workers and engineers by remote monitoring of the system. [20]

Case Study: A Global Biotechnology manufacturing company

• Company Overview: The U.S.-based company is a leader in Biotechnology which develops and manufactures nutritional ingredients using cutting-edge, proprietary technologies. The company operates in more than 10 countries and has a product portfolio of over 2000 products. The company had an annual turnover of 450 Million dollars in 2017.

• Problem Statement: The Company faced a 3.6% quarterly increase in downtime stemmed from an unexplained, overly high level of viscosity in product solution which leads to pipe blockages between the reactor and centrifuge. This resulted in frequent maintenance of pipes, increased waste, reduced productivity and decreased supply capacity. The investigating team was not able to identify the reason for blockage

• Solution: The Company invested in IoT sensors to continuously monitor the data generated from the system. They were able to identify the reason for blockage by the help of analytics. The algorithm was able to identify the correlation of events which lead to blockage. Based on the data generated, the algorithm could provide a prediction alert to the operational team before the blockage occurred again.

• Benefits: The organization was able to reduce the downtime events by 83% and this lead to decrease in downtime cost by 72%. The company is now able to deliver their products on time with an accuracy of 98%. The production capacity also increased by 5.1%. [21]

8. Opportunities and Challenges of Predictive Maintenace:

Manufacturing organizations have lost millions due to unplanned downtime and machine failure. With advancements in IoT and analytics will help organizations save a lot of money and also helps improving the efficiency and productivity. The way in which technology is advancing manufacturers are going to spend billions in predictive maintenance systems. According to the Industrial Analytics Report 2016/17 report that published by IoT Analytics (The organization is a leading provider of market insights for the Internet of Things (IoT), M2M, and Industry 4.0), the top three benefits of Industrial Analytics are increased revenue (33.1%), increased customer satisfaction (22.1%) and increased product quality (11%). The most important application Industrial Analytic is Predictive maintenance (76%) [22]. Hence we can see that Industrial Analytics has helped manufacturing organizations with lots of benefits and most benefits are realized from Predictive maintenance. With the digital transformation taking a huge pace in the coming years, every device is going to be connected and with IoT becoming the next big technology in the coming years we can see that manufacturing organizations can be benefitted a lot. The intense competition in the manufacturing industry is driving every organization to streamline their operations and become more efficient in terms of decision making and productivity and hence Industrial Analytics and IoT is the need of the hour for manufacturing organizations. According to Fortune Business insights, the global predictive maintenance market size was USD 2,387.6 million in 2018 is projected to reach USD 18,551.0 million by 2026. The main drivers for this growth is going to be Internet of things, Cloud computing, Artificial intelligence and Machine learning. [23]

Implementing a predictive maintenance system on the facility floor can be costly. Establishing a complete IoT system with sensors, transmission costs, and detailed analysis is a matter huge cost. We have already seen how predictive maintenance improves an organization's productivity but maintaining the whole predictive maintenance system is also not an easy task. The data that is generated from the IoT sensors needs analysts who can interpret the patterns with help of analytics so it is important that the employees of the organization are trained nicely and should have relevant skills. Interpreting the patterns of machine's performance is just one step, the most important step is decision making about how the whole maintenance should be scheduled, how much resources should be used, response strategy etc. Considering the huge volumes of data that is going to be generated from the assets, the organization should give high priority to data security. The management should have right policies and procedures in organization to safeguard the data. One of the most important challenges that organizations are going to face in predictive maintenance is that the data from the sensors should flow smoothly to the ERP systems so that real time analysis of the operations can be done and also to achieve high level of security. With the advancements in the technologies manufacturing organizations will be benefitted a lot in future but they are also going to face challenges along the way so it is very important that the manufacturing organization do the right risk assessment, understand the opportunities and take informed decisions.

9. Managerial Implications:

When implementing a predictive maintenance system is an organization, management needs to first plan the whole process incrementally. The whole process of implementation is going to very costly. So it is important that implementation should be first done on smaller scale and then after working out issues and hurdles further scaling up the process is recommended. These are the few steps given below when implementing a pilot project in the initial phase. The figure 10 shows the steps.

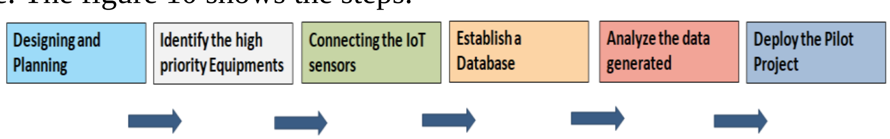

Figure 10: Steps for implementing the Pilot Project

a. Designing and planning: The management needs to first plan the whole process, understand the prerequisites, determine the primary objectives, define the deliverables and requirements, get the right people involved and make a schedule for the plan.

b. Identify the high priority Equipments: The equipments and machines should be first listed according to their impact on production capacity and maintenance cost. There might be cases where critical machines get omitted so it is recommended to order them accordingly. We can label essential machines as Class 1, critical machines as Class2, serious as Class 3 and so on. The list should include every machine on the floor. [24]

c. Connecting the IoT sensors: After identifying every machine on the floor, the next step is to connect the sensors. The sensors should be first connected to the essential or Class 1 machines as loss of any essential machines can result in plant outage and huge loss of production hours. Then Class 2 machines should be connected as the loss of Class 2 machines can reduce the productivity level by 30% - 40%. This helps organizations to avoid cases where a critical machine is not connected due to which unplanned downtime can take place.

d. Establish a database: After connecting the sensors, the next step is to establish a database where all the data generated from the machines are collected. The data collected should be checked periodically to avoid misinterpretation of data which can result in false maintenance requests. The database should also be secured to avoid data loss which can be very costly to the organization.

e. Analyze the data generated: This is the most important stage which analyzing the data and predicting the faults. This stage requires people with right skills and training to accurately interpret the data from different sensors. The model should be developed carefully as a good robust model will increase the not only the productivity but also the efficiency of the organizations. The analysts should carefully consider what kind of machine learning algorithms or advanced statistical approaches would fit best for the analysis. A good model will help organization gain huge competitive advantage.

f. Deploy the Pilot Project: After completing the five basic steps, the initial phase should be carefully implemented and properly documented for future use. After deploying the pilot project, the management should carefully evaluate the results with the objectives defined in the designing and planning stage. After evaluation corrective measures should be taken in areas where the results are not satisfactory.

After deploying the pilot project, the management should implement the next phase taking into considerations all the learning from the pilot project. It is important that in further phases, more and more assets are connected to the database by the help of to improve maintenance system. In the next stages, organization can deploy the whole system over Cloud so that maintenance can be done remotely which can ensure better safety of workers. Different business units can also integrate when the when the whole system is online. A successful implementation will benefit the organization a lot and hence the right approach is needed for implementation.

10. Conclusion:

From this research we can see that organizations have earlier faced huge losses due to unplanned machine failures which resulted in decreased productivity and efficiency. We can see how Predictive maintenance can help organization overcome these issues by predicting the machine's downtime which helped organizations reduce the maintenance cost, improve product quality, improve customer satisfaction and save huge amounts of money. We have seen how analytics and IoT improved the whole maintenance strategy of the equipments by considerable margin when compared with traditional approaches. The industrial cases discussed helped us understand how companies were benefitted from this approach of maintenance. In this paper we can see how a predictive maintenance system should be implemented in the organization and how the whole implementation process should be scaled up.

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