Intelligent Control and Automation, 2025, 16(1), 1-18
https://www.scirp.org/journal/ica
ISSN Online: 2153-0661
ISSN Print: 2153-0653

Making Predictive Maintenance a Reality

Subash Senthil Mohanvel

West Pharmaceutical Services, Exton, USA
Email: Subash.mohanvel@gmail.com

How to cite this paper: Mohanvel, S.S. (2025) Making Predictive Maintenance a Reality. *Intelligent Control and Automation*, **16**, 1-18.
https://doi.org/10.4236/ica.2025.161001

Received: December 8, 2024
Accepted: January 23, 2025
Published: January 26, 2025

Abstract

While Artificial Intelligence (AI) is leading the way in terms of hardware advancements, such as GPUs, memory, and processing power, real-time applications are still catching up. It is inevitable that when one aspect leads and other trails behind, they coexist in life, as is often the case. The trailing aspect cannot remain far behind because, without application and use, there would be a dead end. Everything, whether an object, software, or tool, must have a practical use for humans. Without this, it will become obsolete. We can see this in many instances, such as blockchain technology, which is superior yet faces challenges in practical implementation, leading to a decline in adoption. This publication aims to bridge the gap between AI advancements and maintenance, specifically focusing on making predictive maintenance a practical application. There are multiple building blocks that make predictive maintenance a practical application. Each block performs a function leading to an output. This output forms an input to the receiving block. There are also foundational parts for all these building blocks to perform a function. Eventually, once the building blocks are connected, they form a loop and start to lead the path to predictive maintenance. Predictive maintenance is indeed practically achievable, but one must comprehend all the building blocks necessary for its implementation. Although detailed explanations will be provided in the upcoming sections, it is important to understand that simply purchasing software and plugging it in might be a far-fetched approach.

Keywords

Predictive, Predictive Maintenance, How to Achieve Predictive Maintenance

1. Introduction

Many articles I have read or heard about in seminars discuss predictive maintenance and its benefits. Numerous tools are also showcased, and with Industry 4.0 in full swing, one cannot deny that this is a hot topic and the way of the future.

With AI leading the charge into the future, there are many models that can be utilized to achieve predictive maintenance. However, there is often a lack of explanation on how to implement predictive maintenance in a factory setting. It is important to understand that achieving predictive maintenance for a factory is not as simple as flipping a switch. Nevertheless, there are certain pieces of equipment, such as motors, pumps, compressors, or fans, for which predictive maintenance can be achieved to a certain degree using sensor technology to predict failures with vibration. However, in a factory setting, there is a lot more equipment, parameters, and large machinery, and the path to predictive maintenance needs careful planning. This article aims to explain how to make this happen.

2. Understanding the Road to Predictive

There are many building blocks that make up the road for predictive maintenance. The foundation that helps build a roadmap for predictive maintenance is data. Almost everyone knows it! Without good data, predictive maintenance cannot be achieved. However, there are many steps before that, and that's what this article aims to point out. With this paper, I am hoping the path becomes clear and that one can adopt the path to predictive maintenance.

2.1. Data

It is widely recognized that data serves as the foundation for predictive maintenance. Most people understand that data is crucial for driving decisions. When using a predictive model, you need quality data to train it. Thus, data is indeed the cornerstone of predictive maintenance. Data is everywhere. In an organization, data evolves depending on how your systems are set up and practices are implemented. It evolves over time, settles down, and takes on a pattern. Below is a graph that explains how data can reach maturity. However, maturity does not necessarily mean it is good data. This is a fundamental concept one needs to understand. Most companies focus on selling their product, but very few guide you through the data journey.

But let's understand how we obtain data. This is a key aspect that is often not discussed or explained. Data is simply the outcome of good practices.

The linear progression below (Figure 1) illustrates how data maturity occurs

Figure 1. Data maturity.

over time. Initially, when processes settle in, data is not yet at a point where it can be fully harnessed. However, with time and good practices, it begins to stabilize and can eventually be utilized.

2.2. How Do We Good Data

Data is just an outcome. So how can it be created? Having worked in this domain for more than 22 plus years, I have taken the liberty of classifying it into three different parts. When all of these come together, one can be confident that the path to good data is set. However, constant validation is necessary to ensure that the data is correct and remains validated. As you can see in **Figure 2**, good data is made up of good maintenance practice, process control, and ease of use of the system. Data is the output of the three put together.

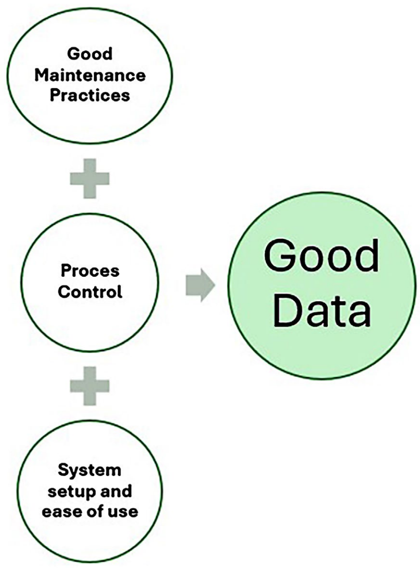

Figure 2. Data equation.

2.3. Good Maintenance Practice

Good maintenance practice is the foundation for data, which, in turn, forms the foundation for predictive maintenance. Thus, one can confidently say that this is the foundation, and getting it right is key. There are numerous books that explain good maintenance practices, and this is a topic in itself that could fill an entire book. However, I would like to explain some of the key maintenance practices that are important and must be implemented to obtain the right data.

Let's work backward from the data to identify all the good maintenance practices that need to be implemented.

Data that is needed for predictive maintenance is an outcome of the maintenance practice. The maintenance practice is, in turn, made up of the following items and a few are explained below while the others are self-explanatory.

I. Equipment/Machinery. E.g., Gearboxes, Motor, etc.

a. Criticality of the equipment with ABC indicators.

II. Manufacturer documentation/Company own manual about the information of the equipment.

III. Spare parts/MRO. What is the equipment made up of?

IV. Maintenance history.

V. Device connectivity.

VI. How the maintenance process is executed.

VII. Documentation.

VIII. Continuous improvements.

I. Equipment/Machinery. E.g., Heavy machinery, Gearboxes, Motor, etc.

Equipment or the machine represents the physical aspect. Example of heavy machinery Equipment. Refer to Figure 3 below [1].

Image Source:
https://www.equipmentworld.com/construction-equipment/article/14966285/motor-graders-have-gotten-better-at-one-thing [1]

Image Source:
https://www.indiamart.com/proddetail/heavy-duty-motor-14097320112.html [2]

Figure 3. Examples of equipment.

Equipment, as shown in the example above (Figure 2), is the physical representation [2].

II. Manufacturer documentation

As part of a physical equipment purchase, it usually comes with a manufacturer's manual containing detailed instructions on how to maintain it and monitor critical process parameters. This documentation is often quite extensive, and it's important that the core contents are digitally translated or available in a format that is easy to use. Simplifying these materials is often the toughest challenge!

When it comes to maintaining the equipment, it is critical that the manufacturer's instructions are followed and executed accordingly. One key activity that should be undertaken is digitizing the instructions so that they can be easily incorporated into maintenance activities. This is where a Computerized Maintenance Management System (CMMS) comes into play. What differentiates one CMMS from another is the ease of use and the effectiveness of data capturing.

III. Spare parts/MRO

Every piece of equipment or machinery is made up of spare parts. In a factory with thousands of pieces of equipment, spare parts organization and effective usage become key. Companies need to ensure there is enough inventory without having so much that it becomes an overhead on cost and maintaining them. CMMS systems can assist the organization with this. However, the first step, even before utilizing the system, is to organize the inventory in a way that allows the parts to be found easily and managed effectively. There are many options available in the market for spare parts organization. It is important that companies choose the right strategy before implementing it.

2.4. Process Control

Process control is the step where one tries to establish a practice. For example, an instance of process control is holding daily stand-up meetings in the maintenance shop to review critical items that need to be addressed and what was left the previous day. Another example of process control is ensuring every important activity gets documented, such as issuing or taking spare parts for a job or tracking and entering time after the work is completed. There are many such examples of process control, but it's important in any factory to establish such good practices. There are tons of articles and books available that explain how to establish these concepts. One should ensure there is a measurable outcome so the practices can be tested. For example, as spare parts are taken out, the maintenance team should be able to measure high-moving parts by classifying them with ABC indicators. Each process control should have a measurable outcome to allow for course correction. A few processes measurable indicators are explained below in **Table 1**. The goal of this article is to ensure that good process control is in place to make predictions a reality.

2.5. System Setup and Ease of Use

This is one of the very important steps, as this is where it all starts to come together.

One could have great maintenance practice and the right process control, but if the system is not flexible enough to accommodate the data and incorporate the process, then it starts to fall apart. There are many CMMS systems available on the market to cater to these needs. Pick the one that suits the budget and practices. Having been in the SAP space for a very long time, I can confidently say that due to its integration and functionality, SAP is one of the top systems I would recommend as your CMMS. However, any system can become complex depending on how it's set up. For example, in one of the plants prior to the implementation of CMMS, the maintenance order was printed by the maintenance planner, and the technicians needed to write data on the paper provided. Even though it seems like you have control, there are gaps in the data entry process, leading to potential data loss when inputted into the system. So, how do we promote ease of use? Achieving this can be complex. Mobility can be a step forward in enabling the ease of use of the system. Ensure the CMMS system has the right mobile apps and functionality tailored to the technician or user group. User experience is a significant part of the deployment, and the user group to which the solution is being catered needs to be ensured.

Table 1. Explains some of the measurable indicators.

Process	Measurable indicators	Benefits provided by measurable indicators
Maintenance request	Request per day	Assess the crew size needed
Maintenance request	Requests across departments	How the solution/practice implemented is effective across departments
Maintenance order/work order	Spare parts usage	High moving parts and classification through ABC indicators
Maintenance order/work order	Equipment most impacted	What equipment is failing most often and take necessary action. Manufacturer issue or maintenance issue
Maintenance order/work order	Time taken to complete each work	Understand the crew size and the complexity of the work needed
Maintenance order/work order	Maintenance plan or Preventive maintenance plan vs. unplanned work vs. Breakdown	Understand the nature of the work posed for the team. 80% plus orders should be Preventive maintenance job and that indicates that the maintenance practices are going in the right trend
Post fix	Analysis and root causes	Grouping data by the causes help to identify key issues and take measurable actions

Making the functionality built into the CMMS system available on mobile devices does not automatically make it user-friendly. Consider how the end user interacts, what's important, where pictures can be useful, reducing the number of clicks, etc.—all play an important role in making the system easy to use. One example is with the iPhone: if you don't know the meaning of a text, you can click it and look up a translation right there. Making it easy requires a detailed thought process. Simple examples include facilitating attachments or having instructions readily available. Consider a scenario where the process is implemented for corrective maintenance, where you train your users to create notifications. The details about the problem can be found in the notification text. When the planner plans it and converts it to the Maintenance Order, it's crucial to ensure the instructions from the text are copied over to the order.

Additionally, the end user might continue to update the text in the notification. How do you ensure the technician gets all the information necessary to do the job right? One might argue that the technician can check the notification text themselves. Yes, it can be done, but adding screen clicks adds steps that the user might or might not follow. This is just an example of how the process/mobility should be implemented to make it easy for the end user. The same process should be applied across all items. This could be an endless process, but with the right team who understand the user group, foster creativity, system knowledge, and recognize the importance, you could be off to a good start.

Using the above example, apply the same thought process to the following process with respect to data collection. There is much more than what's provided below in the list, but this should give one an idea of how to make it happen.

1) Maintenance planning

a. Searching of the work orders and how to prioritize them.

b. What's due for today and the backlog that got missed out.

c. Ensure the team, or the individual, has the workload for the day.

d. Individual work order list.

2) Execution

a. What parts can be used for this equipment.

b. History of the repair.

c. Is there a duplicate request.

d. Documentation search based on the problem.

e. Logging of time and parts.

3. Building Blocks in Your Maintenance Process Towards Predictive

Now that the criticality of data is explained, the next step in the process is to set up the foundation for the journey to predictive maintenance. This is one of the most important concepts to understand, as it explains the journey towards predictive maintenance. The foundation for this journey is your CMMS system and all the concepts explained as part of data management.

Please note that the data is the outcome from building block 1 to building block 3. It's important to understand that without good data, predictive maintenance is not possible.

Building blocks are explained in the upcoming sections.

3.1. Building Block 1: CMMS System as the Foundation

CMMS is not a new concept and has been around for many years. Numerous articles and books have already explained what a CMMS system does and how it should be implemented. To maintain the focus of this article on predictive maintenance, I will highlight only a few critical aspects needed for a CMMS system. This is not a comprehensive list, but it should provide a guideline on what to expect.

It's important to have the foundational model built, and CMMS is a crucial component. The system you choose should be able to adapt and also provide guidance on best practices so that the organization can scale towards predictive maintenance and make the predictive dream a reality.

To achieve this, one needs to understand how to choose the right CMMS.

What's the definition of a good CMMS system?

- **Scalability**
- Ability to take on many users without affecting performance.
- **Reliability**
- Ability to keep running with minimal downtime.
- **Ease of use**
- This connects with the data explained above and should be easy for the team to use.
- **Mobility**
- Ensure that all critical data, such as order confirmation, Equipment BOM, order list, notification list, and other essential information, is available on mobile devices for ease of data entry and quick reference.
- **Integration with other functional areas**
- Maintenance operations rely heavily on spare parts, external contractors, and non-stock parts. The CMMS system should seamlessly integrate these with procurement and financial systems, ensuring that maintenance requirements are fulfilled, and costs are tracked.
- **Features of CMMS**
- Asset management, work order scheduling, spare parts management, preventive maintenance, document management, reporting, and integration with other systems are key components.
- **Support and Upgrade**
- Any system used by a user should have adequate support and the capability for future upgrades.

3.2. Building Block 2: Equipment Criticality

The second building block in the puzzle is to identify the critical equipment that affects the reliability of the factory. If any of this equipment is down, production is impacted, leading to production loss and increased cost.

Many in the industry underestimate this concept and have often heard the term "maintenance is just maintenance." This clearly indicates a lack of understanding and reveals the limited knowledge of some individuals. If production and operations are responsible for output, then the factory must be in good condition to run effectively and generate profit. Production and maintenance are dependent on one another. When there is a symbiotic relationship between them, one can see a significant improvement in the productivity of the factory.

Equipment Criticality:

Identified with ABC indicators, this system helps stress the importance of the criticality of the equipment: "A" being the highest, where its breakdown would significantly impact production, "B" indicating a potential impact, and "C" representing lesser value. Depending on the maintenance practices you have adopted, this system could include more values, but the concept of equipment criticality remains the same.

When preparing for predictive maintenance, choosing pilot equipment is one of the first steps. Criticality plays a role in selecting pilot equipment. I would not recommend choosing the most critical equipment for a pilot; instead, pick one with lesser criticality so that a learning process can be established. Every factory or company may vary in size and complexity depending on their learning process. One should understand that predictive maintenance is a journey and not a switch to be flipped. Patience needs to be exercised!

3.3. Building Block 3: Maintenance Plans and Regular Maintenance

Maintenance plans:

It's important that all equipment have a maintenance plan. If you are just starting to work on this, begin with equipment classified as criticality A, then proceed to B, and so on. The maintenance plans should be implemented in stages or can proceed in parallel. Below are two categories that can be addressed in stages or, in some cases, in parallel.

1) Stage 1: Calendar-based plan

2) Stage 2: Hours-based plan

Stage 1: Calendar-based maintenance plan

In this stage, you have the maintenance plan create work orders or notifications based on a schedule. It's similar to taking your car to a mechanic shop every year for an oil and filter change. Will keep the explanation brief, as this is a general concept that most are aware of. Once all the maintenance plans are set up, the system will generate orders based on the desired interval and lead time. Planning is then executed regarding—who will complete it and when. It is then handed over to the technician for completion.

Based on the manufacturer's recommendations or the crew's knowledge base, the plan be set up. While this has its advantages, one cannot be certain if the tasks are truly necessary or if they are executed at the right time. This is the hidden downside, where technician time and parts are consumed, potentially leading to wastage. This is the problem that predictive maintenance aims to solve: determining if a job is truly needed and when it should be done so that time and money are utilized more effectively. As this approach is explored, one should keep in mind that reliability should not be compromised.

Stage 2: Hours-based maintenance plan

An hour-based maintenance plan is executed once the equipment completes a specified runtime. For example, maintenance on a motor can be performed once it has run for 100 hours. The plan can be set up based on manufacturer recommendations or existing knowledge. An hours-based maintenance approach is a step forward, as it allows maintenance to be scheduled based on data or actual runtime. Feedback can also be incorporated into this process to adjust the frequency based on outcomes, potentially reducing maintenance efforts. However, challenges exist in production regarding how to track runtime hours and associate them with the corresponding equipment. One of the main challenges is determining how to accurately capture hours and link them to the equipment.

3.3.1. Challenge with Hours on the Equipment

Challenge to solve: How can we capture hours for the equipment?

There are a few options here.

Option 1: Data Captured Manually

In this option, data is collected manually and entered into the equipment system. Collecting data manually may involve recording it in a notebook first, then entering it into the CMMS system or through a mobile device. While this option has its advantages, there are downsides, as it requires careful planning and execution. This adds more work for the planner and the crew. In maintenance, we must be very careful about adding work to the team, as it might not get done. Additionally, if you have hundreds of pieces of equipment, data collection and entry can become a significant burden.

Option 2: Data Captured Through the Production Run

If you have a production module implemented as part of your ERP system, then you likely have access to this data. When production completes the production run, the machine and labor hours are typically captured as part of the closeout process. If this is based on standard hours, it's not worth pursuing this route. However, if actual production hours are captured, this data can be used to record readings for the equipment associated with the production line. In SAP, standard setups can be utilized. Another option I implemented in the past was to cascade the readings to the equipment associated within the production line hierarchy to all relevant equipment. One of the challenges here might be that the equipment associated with the hierarchy might not be running for the product being produced. If such variables exist, then the accuracy could be compromised.

Option 3: Interface the PLC

Determining if the equipment is truly running is one of the main challenges. One of the best options would be to interface the data from the PLC connected to the equipment. If a PLC is available and you have a historian collecting the data, this could be an effective option. This method is beneficial because it provides an end-to-end automated solution. Start with your critical equipment list and choose a pilot from it. For the pilot equipment, begin with the following approach by answering these questions.

- **Do the right tags exist in the PLC?**

There could be numerous tags being collected for specific equipment in the historian, but the maintenance department might only be interested in a select few that are critical for maintenance. The unit in which this is recorded also plays a crucial role in consuming the tags. For example, the tag sent to the historian might indicate if the motor is on or off. However, maintenance would need the hours run, which must be programmed to ensure the correct number of hours is sent at the right intervals. The data would also need validation, potentially using the historian charts.

- **What are the possible methods for connection and data transfer to the CMMS? E.g., OPC/UA.**

It's important to consider how to transfer the data to the CMMS system. The data might reside in the plant network/operational technology (OT), while your information technology (IT) network could be separate. Network segmentation might be in place to prevent disruptions.

- **How is the tag programmed and how will data be transformed for the CMMS?**

While this may seem simple, it can cause many issues post-data connection. It's up to the engineer who programmed it, and the standards followed. For instance, if rollover exists, transformation needs to be done to ensure the right data is sent to the CMMS system. Rollover is just an example, and there are multiple ways to program the tag. This concept needs to be thoroughly discussed with the engineering team before establishing the connection.

3.3.2. Regular Maintenance

Preventive maintenance should account for 80% or more of the work orders associated with regular maintenance. However, unforeseen events can occur, resulting in the creation of a breakdown order or a regular maintenance order, depending on the circumstances. It's important that this data is classified differently and is also available for the equipment for which predictive maintenance is planned.

3.4. Building Block 4: AI—Machine Learning Models

As you progress with the building blocks explained above, it's important to begin conversations with your Artificial Intelligence/Data Science team. Understanding this block to some extent is crucial, as this is where potential pitfalls lie. I've seen organizations where block 4 is executed without attention to the preceding building blocks, resulting in stalled progress.

AI or data science is a field of study on its own, and the objective of this article is merely to tap into the benefits of AI. There are numerous articles specifically about AI for those interested. However, to keep this article focused, I will keep it concise so that the basic concepts are covered, with the main emphasis on how AI and the other building blocks described can make predictive maintenance practical.

With recent advancements in AI, many models have emerged. Selecting the right model is important, as they are critical to the process. One can find many models by searching online. It's crucial to understand each model and its pros and cons. Relying on your AI/Data Science team is one of the best strategies. By providing them with data breakdowns and clearly defined expectations, they can develop a robust model. However, validating the outcomes still relies on business professionals or those with knowledge of both business and technical aspects.

In this article, I will provide an overview of the learning methods and models. There are more learning methods and models, but this article aims to provide an overview so that one can understand the basics.

Machine Learning Methods:

- **Supervised Learning:** The input data to the output data is clearly defined to train the model.
- **Unsupervised Learning:** The model identifies patterns using input data for prediction.
- **Reinforcement Learning:** It learns from experience, receiving feedback for both good and bad outcomes to improve future predictions.

Machine Learning Models:

- **Regression:** Uses data from previous trials to predict outcomes (e.g., Weather Forecast).
- **Decision Tree:** Divides the dataset to answer questions for prediction (e.g., Credit Scoring).
- **Classification:** Classifies the dataset to answer questions (e.g., Disease Detection).
- **Neural Networks:** Mimics the human brain to predict outcomes.

There are many more models available in this rapidly growing field. Many models can be combined, offering infinite possibilities. You can select any model for data prediction, relying on your data science team's expertise [3].

4. Connecting the Blocks to Make Predictive Maintenance Possible

Since a picture speaks more than words, I am going to attempt to explain this with visuals and text, as this is the critical piece that makes predictive maintenance possible. Additionally, the path to predictive maintenance is explained in several steps to make it easier for the team to apply it practically and make it a reality.

4.1. Step 1: Understand How the Blocks are Connected to Each Other

As you can see in the picture above (**Figure 4**), each block feeds data into the next. Maintenance practice and process enforcement serve as the foundation. The process is implemented in the CMMS system, which is used to set up equipment criticality. Based on the criticality, maintenance plans are built, and the pilot equipment is chosen for predictive maintenance. Now that the block connections are established, let's see how to prepare for predictive maintenance.

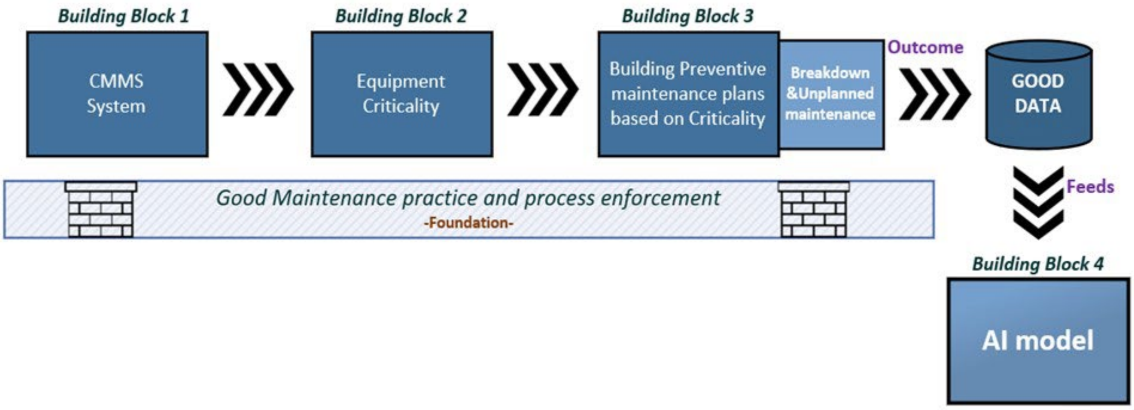

Figure 4. Explains how blocks are interconnected.

4.2. Breakdown of the Road Map and How to Execute It

This step is crucial as it explains how each block is broken into detailed steps and how to execute these steps to enable predictive maintenance.

In the picture below (Figure 5), you can see that the blocks are broken down into individual steps, with each step mapped to a block. This visual representation should help one understand how each block is further subdivided for execution.

Setup: In Figure 4, the setup is the initial step that needs to be constructed, establishing connectivity with the shop floor. There are various affordable tools available for this purpose. PLC connectivity types include OPC/UA, TCP/IP, and different kinds of PLC drivers. The key is to have a platform capable of reading data. Options include platforms like Wonderware and Ignition (Inductive Automation). Implementing a new SCADA system is not necessary; you can use an edge platform [4] to read data from the plant floor devices and store it in the historian. Programming and rollover for the tags need to be coordinated with the engineering team, as this forms the foundation of the setup. The engineering or automation team should be responsible for establishing this setup.

Block 1 & 2: In Figure 4, Blocks 1 & 2 represent the second step where data collected by the SCADA/Historian from the PLC is sent to the CMMS system. This involves building an interface to the CMMS system for data transfer. There should be a cross-mapping between the equipment data sent by the PLC and the CMMS system. This might require custom development, as it's not commonly seen. However, with current technologies, this is relatively easy to achieve.

Block 3: In Figure 4, Block 3 shows how the maintenance plan setup for the critical equipment responds to the data received. This is a standard feature in most CMMS systems. Being familiar with SAP, I find this feature quite seamless within SAP. Measurement readings are recorded against the measurement point set up for the equipment. The maintenance plan generates a maintenance notification or order depending on the configuration. You can adjust how soon you want to receive the output from the maintenance plan.

DATA Block: In Figure 4, the DATA Block is the output generated by the maintenance plan in the previous block, represented by the maintenance order or notification. This output needs to be validated by a maintenance department expert, who decides whether it should be canceled or executed. This step is crucial as the data begins to feed into the AI model for learning. If the maintenance order is executed successfully, the output also reinforces the AI model's learning. During this unexpected breakdowns or maintenance might occur; these work orders should also be executed, with the data fed into the AI model.

Block 4: In Figure 4, Block 4 explains the integration with the AI model and its output. The AI takes in three inputs: first, the runtime hours from the PLC; second, the validation of outputs from the CMMS system maintenance plan, indicated by the maintenance order or notification; third, the maintenance execution of the plan output. All three inputs are critical for the model's learning.

As the AI model starts to learn, it is important to continuously refine and correct the learning. This is a critical step in the process, and it is one of the areas that can hinder predictive maintenance from becoming a practical application. There needs to be a constant feedback loop with business users so that the data can be validated. As the journey progresses, you will start to see the predictions become more accurate, and that's when the AI model begins to mature.

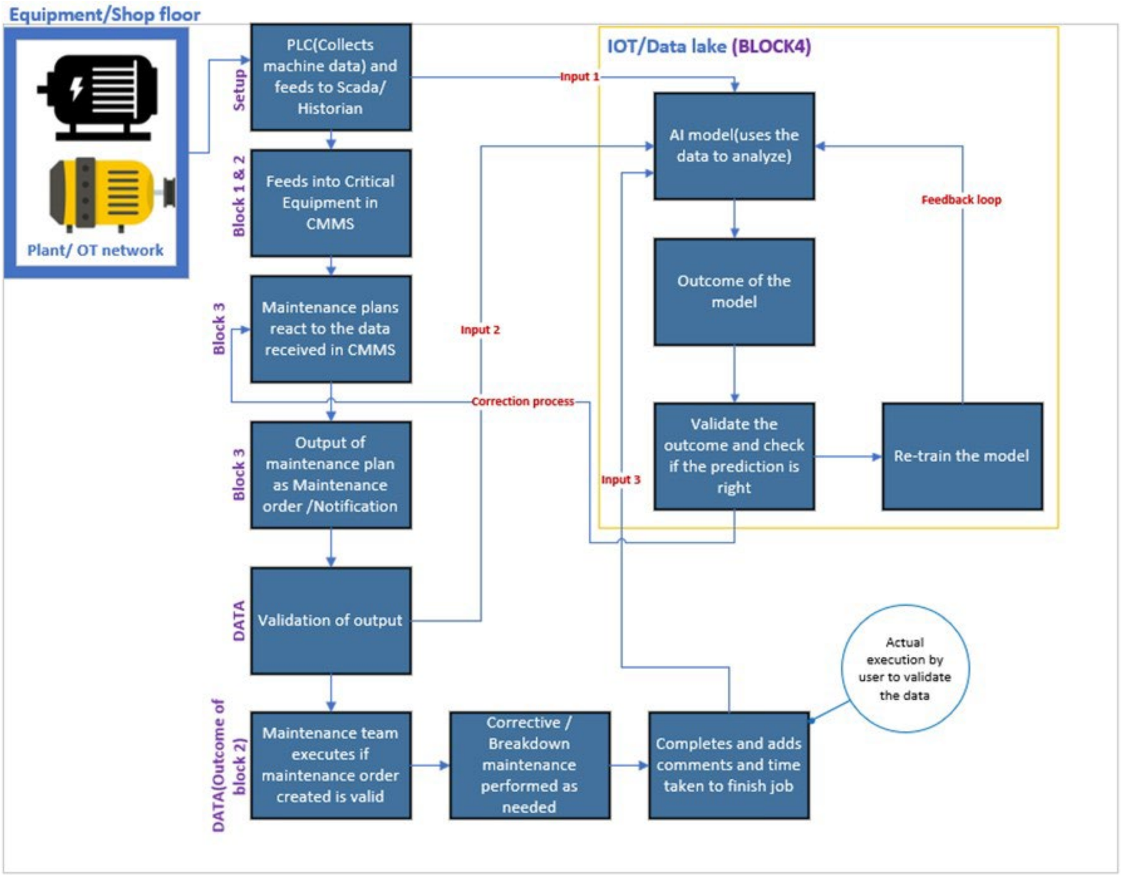

Figure 5. Explains the detailed explanation of the blocks and its execution.

Roles or Teams Involved

As you can see in Figure 4 and Figure 5, different user groups are involved in achieving this effort. As humans, we are inherently collaborative, and this process or journey is no different. However, from my perspective, there needs to be a role or visionary who understands the end-to-end flow. This group or person should have the vision to pull everything together.

The roles or teams needed are:

1) Engineering: Responsible for programming the PLC and providing the respective tags needed to collect data. This team is also responsible for installing the sensors, connecting them to the access point, and accessing the data.

2) Development/IT: This team is responsible for developing the interfaces from the Historian to the CMMS. They will also be responsible for sending the data to the IoT.

3) Business Lead: These individuals are the end customers and should be able to provide input on the outcomes.

4) Data Science: While this could fit into the IT team, it is important to highlight it separately as this team is responsible for how the data should be handled, selecting the appropriate AI model, training the model, and analyzing its outcomes.

5) Visionary: This is a new team and is not the same as project management. In my view, this group/person brings all the teams together and maintains a roadmap vision. I have not seen such a team before, and it could be part of either the IT team or the business.

5. Quick Wins in the Journey

While the above steps potentially work for all, there are sensors and devices available that can help achieve quick wins for businesses. This could also serve as a stepping-stone as the predictive thought process is introduced to users, helping them progress and support the approach.

I have had the opportunity to work with a couple of companies, namely Waites and Proaxion. Please note that I am not promoting either of them, but I wanted to point out that using these techniques or technologies can help a company get a head start on their AI journey. These companies offer sensors that can be installed on equipment to provide predictive maintenance capabilities.

Waites sensors, built with reliable 316 stainless steel and advanced ImpactVUE® technology, provide extensive vibration and temperature monitoring with a 3,000-foot radio range. Offering global certification and support in 13 languages, Waites ensures worldwide service and integration. A team of international experts continuously analyzes equipment to enhance maintenance practices, significantly altering maintenance strategies when collaborating with on-site teams. The system can deliver a swift return on investment, typically within four months, offering benefits such as increased asset life, reduced maintenance and energy costs, lower spare part expenses, and higher facility capacity [5].

On the other hand, the Proaxion system provides a user-friendly and effective solution for improving plant reliability. It features straightforward installation without the need for special tools, training, or IT integration, and offers a completely wireless setup. Its intuitive interface is accessible to all users, regardless of prior vibration analysis experience, with information that is easy to interpret. The system supports effortless connectivity outside of corporate networks, embodying true plug-and-play functionality [6].

Both companies offer similar solutions, but for the intent of this paper, the focus will be on technology and how the predictive maintenance thought process can be applied.

In Figure 6, as shown above, a sensor is physically connected to the equipment. The sensor's job is to collect data from the equipment and send it to cloud storage. Various types of data can be collected, but the primary focus is on **vibration**. Essentially, it measures how much shaking the equipment encounters and how it could potentially affect the equipment. Vibration analysis on equipment is a field of study in itself. However, with advancements in AI, the data can be fed to an AI model for predictive analysis.

One approach is to implement the solution as is. I have heard positive user feedback about its effectiveness and the savings it generates at the plant. This could be a Phase One approach.

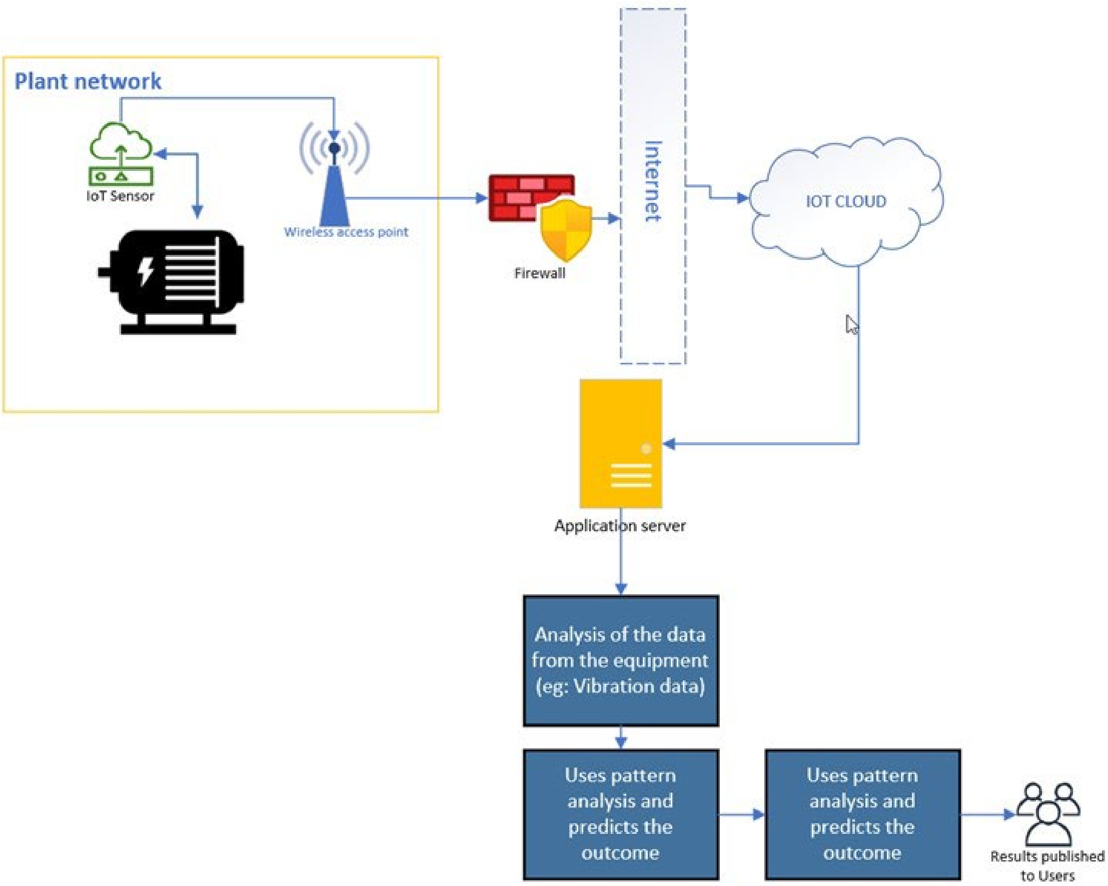

Figure 6. Vibration monitoring for equipment and predicting the outcome.

The second phase could involve using your team to analyze the data. This means purchasing the hardware only and taking responsibility for the data collected.

The third phase is to feed the data into the AI model, as explained in section 6.2 above, taking control of both the data and the predictive analysis.

As you can see in Figure 7 above, as the AI journey matures and the teams gain more understanding, the next set of inputs can be fed into block 4 or to the AI model.

6. Conclusions

In concluding my thoughts, this paper aims to offer a clear, step-by-step method for implementing predictive maintenance as a practical application. Like any project, unforeseen challenges will arise, adding an element of excitement and an opportunity for learning. With over 22 years of experience in industries such as construction, mining, pharmaceuticals, and utilities, I have noticed a consistent pattern in problem-solving approaches. Delving deeper allows you to cultivate a visionary outlook, but it's essential to stay grounded in the details to truly grasp the pattern; otherwise, it can be missed. Explaining these insights to others can be even more complicated!

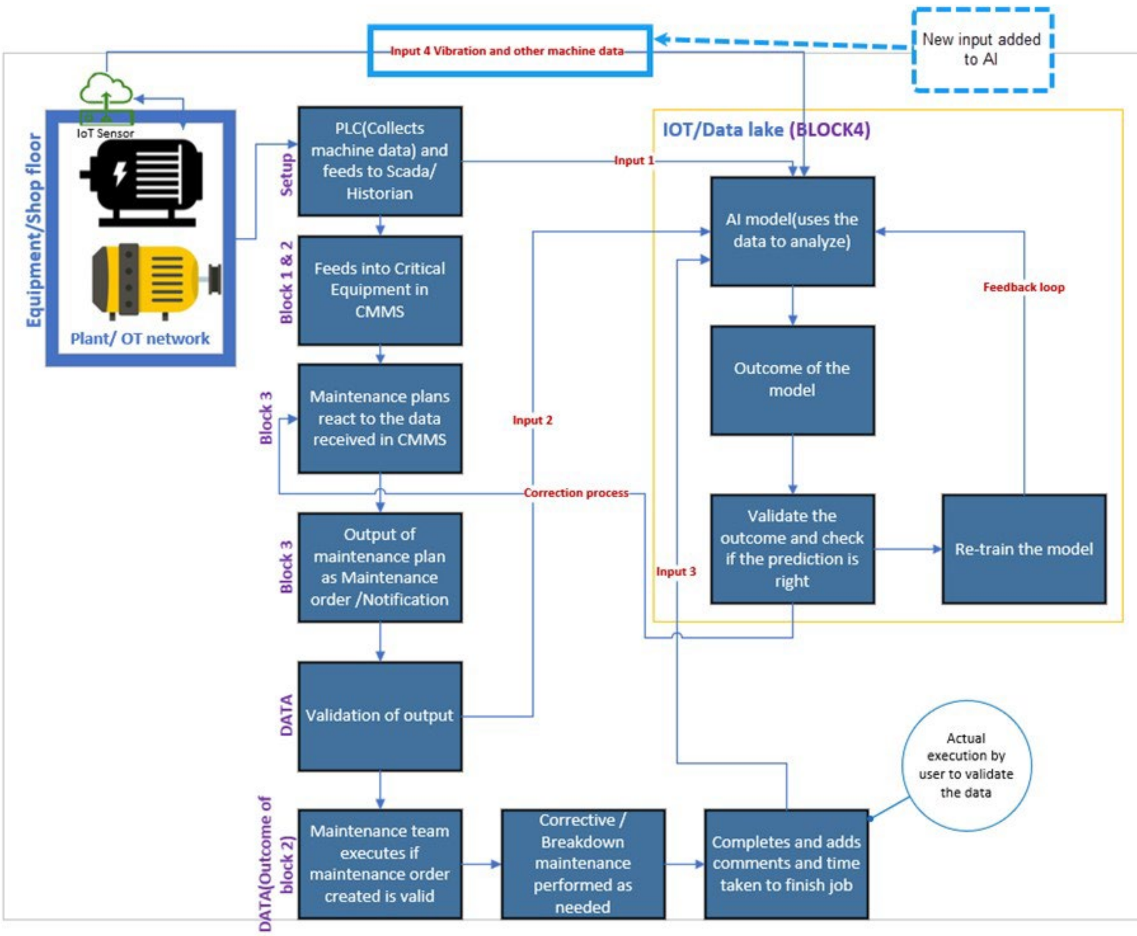

Figure 7. Vibration input added to the AI model.

Understanding patterns helps establish an effective workflow and teaches how to accomplish tasks. This insight comes with experience, emphasizing quality over mere years accumulated; it's about grasping the intricacies behind each experience and continuously refining your approach.

As the saying goes, "There is more than one way to skin a cat." The journey to implementing predictive maintenance can take various paths. In this paper, I've chosen the approach to break the process into distinct blocks, making it easier to understand and execute. This simplifies comprehension and aids in connecting the dots, making predictive maintenance a reality.

Prerequisite

A background in maintenance could be beneficial for understanding the document.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Staff Report (EQW) (2016) Motor Graders Have Gotten Better at One Thing. https://www.equipmentworld.com/construction-equipment/article/14966285/motor-graders-have-gotten-better-at-one-thing

[2] Indiamart (2015) Heavy Duty Motor. https://www.indiamart.com/proddetail/heavy-duty-motor-14097320112.html

[3] Danielkievych, A. (2023) Top 6 Machine Learning Techniques for Predictive Modeling. https://forbytes.com/blog/main-machine-learning-techniques/

[4] Inductiveautomation (2002) Ignition Edge. https://inductiveautomation.com/ignition/edge

[5] Waites (1998) Waites Wireless. https://waites.net/en

[6] Proaxion (2014) Proaxion Wireless. https://proaxion.io/