WHITE PAPER

A common-sense approach to asset performance management

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The problem

Manufacturers face complex challenges from supply chains pressure, reshoring initiatives and the push toward advanced manufacturing. Traditional issues of costs, quality, reliability, productivity, customer satisfaction and workforce constraints remain. Reliability sits at the center. When assets perform, everything else follows. When they don't, the impact spreads quickly.

Maintenance and inspection practices have long supported preventative maintenance (PM) techniques such as routine, periodic or time-based and condition-based monitoring (CBM) to maintain equipment, machines and devices. Vibration monitoring is a good example of CBM. Even with these approaches, some assets are left in reactive or run-to-fail (RTF) mode. Reliability-centered maintenance (RCM) and risk-based inspection (RBI) strategies have been widely adopted. Subject matter expertise has also been relied upon to understand the sources of degradation and failure, as well as why they occur and under what conditions. This expertise can be captured in a failure modes and effects analysis (FMEA) library, though it may not address every possible asset or failure mode. Computerized maintenance management systems (CMMS) have also evolved into enterprise asset management (EAM) systems, whose primary jobs are to schedule and execute work orders and record the results, including work effort and costs.

What approaches do you use to develop asset strategies?

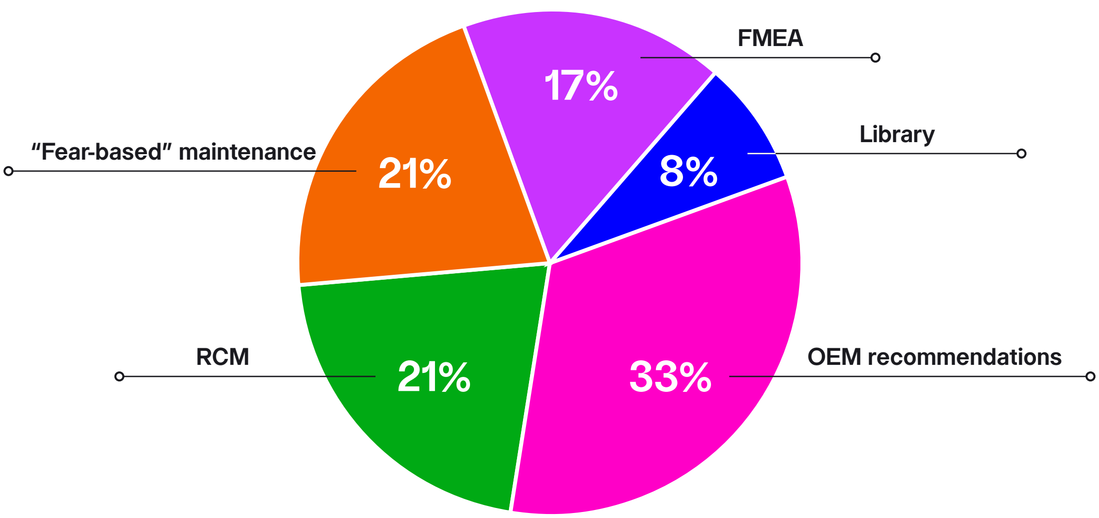


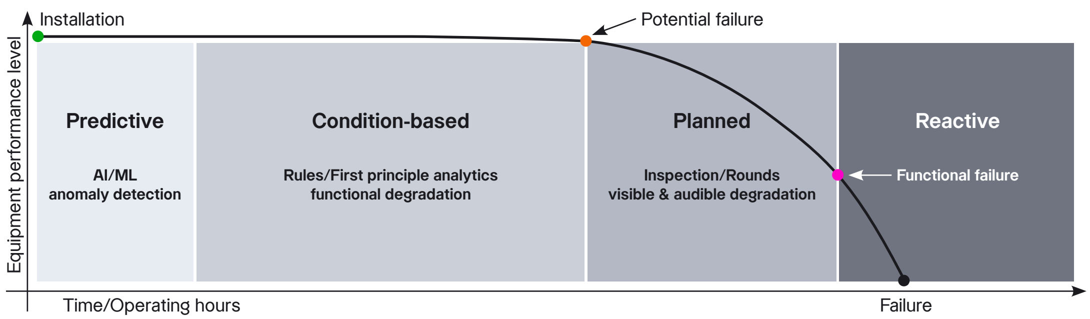
Figure 1: 2023 survey, asset management professionals

New technologies are shifting the tempo. In the last 10 years, predictive maintenance (PdM) and prescriptive maintenance (RXM) powered by machine learning (ML) and advanced analytics have expanded what's possible. With industrial internet of things (IIoT), such as sensors, edge computing, DataOps, networking connectivity (Wi-Fi, 5G Cellular, ISA 100, OPC UA) and other technologies, organizations can move from reacting to failures to anticipating them. The result is a step change in reliability capabilities.

What is asset performance management?

Asset performance management (APM) brings it all together. It's a decision-making process that aligns strategy, risk and execution to improve asset performance across the lifecycle. It connects people, processes and technology to drive better outcomes: higher availability, stronger reliability and lower downtime.

APM builds on existing approaches, adding intelligence and scale. It detects degradation early, predicts potential failures, performs root cause analysis and recommends prescriptive actions across a series of assets at once. Where teams once relied on spreadsheets and manual analysis, APM connects systems and automates insight to improve accuracy, speed response, save time, effort and cost, and reduce risk.



	Predictive	Condition-based	Planned	Reactive
Equipment risk profile	Very high to high	High to low	High to low	Low
Typical % of population	<10%	40%-70%	30%-60%	20%-30%
Time to react	Best	Better	Minimal	-
Business impact	Very high	High	Medium	-

Figure 2: P-F curve

What has been the impact on maintenance approaches? The industry is shifting from a combination of RTF, routine, CBM and periodic maintenance to a more heavily weighted CBM, along with PdM and RXM applied to the most critical assets. Given low-cost sensors and IIoT, few assets today cannot be monitored cost-effectively. Thus, the number of assets utilizing traditional PM and RTF is decreasing while CBM, PdM and RXM are increasing. However, the rate of uptake is uneven across industries, with large-scale process industries such as refining, petrochemicals, chemicals, mining and power generation leading the adoption. The hybrid/batch and discrete industries tend to lag the process industries, though there are notable exceptions - semiconductor manufacturing being a good example.

What's next? Given the advances in generative AI and causal AI, APM is expected to add PdM and even learning capabilities by the end of this decade. APM will integrate with other systems to optimize operations and turnaround planning over multi-year time horizons while minimizing carbon footprint.

What techniques are you using to mitigate asset failure risk?

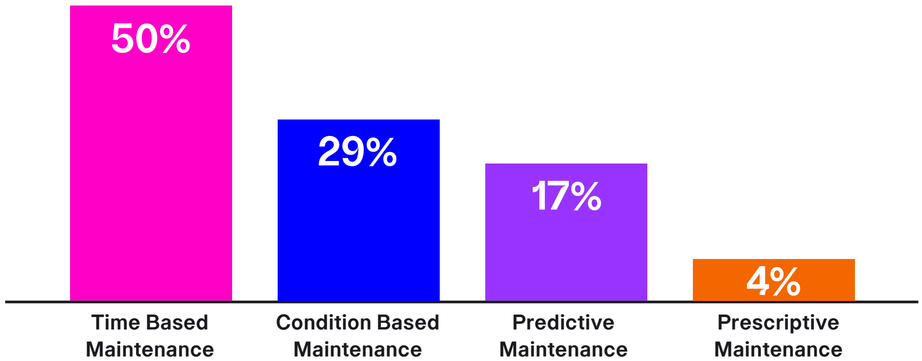


Figure 3: 2023 survey, asset management professionals

It's a crowded and often confusing market

The APM landscape is complex. With more than 20 vendors and overlapping definitions, it's easy to confuse products with full solutions. Let's break this down to better understand the difference between products and solutions.

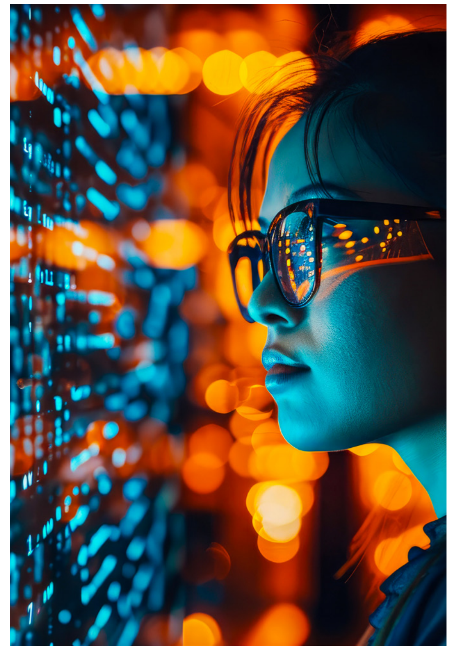
First, a bit of history. The mathematics of ML is well understood and dates to the 1950s. By contrast, modern statistics date to the 17th century, with discussions of probability going back hundreds of years earlier. With today's low-cost, powerful computing capabilities, ML can consume large amounts of data and develop and run their models in real-time. This made it possible to apply ML to the prediction of asset performance,to predict asset degradation and potential failure. These predictive capabilities remain valuable.

Many offerings focus on predictive capabilities alone, identifying anomalies but leaving analysis and action to manual processes. Let's look deeper. APM products with predictive capabilities are often referred to as PdM. They may use proprietary or open-source ML algorithms to identify abnormal behavior in the data stream or anomaly detection. The ML models can be trained to identify known patterns of bad asset behavior or detect unknown bad behavior. The bad behavior implies a root cause of the potential problem. When the behavior can be associated with a known failure mode, such as one in an FMEA library, problem identification is quickly facilitated. Some libraries may contain recommended actions to resolve the problem, such as prescriptions.

That's where the gap emerges. Most APM products stop at the predictive point, but true APM solutions can go further.

APM solutions connect strategy, risk assessment and the ability to trigger external actions (e.g., work orders and notifications, as well as predictive and prescriptive capabilities). This is the inherent limitation of predictive-only products. They leave the heavy lifting of the analysis and resolution to the manual efforts of engineering and maintenance personnel. Note that there are only a handful of APM vendors who use FMEA libraries, either their own or from a third-party supplier. Without that connection, organizations are left with insight but no clear path to act.

APM options



There's no shortage of tools that overlap with APM. Advanced analytics platforms, open-source machine learning frameworks and state modeling tools all play a role but often require deep expertise and manual configuration.

Another category of APM-related software is called state machine modeling or simply state modeling. A state machine model is a mathematical model that groups all possible system occurrences, called states. Every possible state of a system is evaluated, showing all possible interactions between subjects and objects, such as the assets. The idea is to model the entire production system's key assets, specifying various scenarios representing varying degrees of reliability, acknowledging that no asset is available 100% of its lifetime. This allows a design and economic analysis of the system. State modeling is mainly used in an offline mode in the capital design stage and when planning modifications, additions, or removals. It is complementary to APM in that once the APM strategies are developed, they can be modeled under different reliability scenarios to determine the realistic maximum production capacity. It is often paired with other production modeling software in the design stage to optimize the system design.

Manufacturing performance solutions (MPS) add another layer, focusing on throughput, quality and equipment performance. By MPS, we refer to software that is designed to optimize the production process by providing analysis and advisory direction to production engineers and plant floor personnel. This is in contrast to the advanced control and optimization techniques used in large-scale process manufacturing, or from manufacturing execution systems (MES) and manufacturing operations management (MOM), whose functions are primarily to schedule, execute, track, analyze and report.

MPS is different. There are two broad types of this software. First, those that focus on machine, tool and equipment uptime. Their objective is to improve overall equipment effectiveness (OEE), identify bottlenecks and increase productivity. They may include PdM functionality. However, the operators are required to label data when tool failures or quality defects occur. Then machine learning algorithms detect patterns from the hundreds of data items collected from each machine. They also lack an FMEA library, although the operators are building a basic version of one as they label data. This type of software is most often used in the discrete industries but is also found in the hybrid/batch.

The second type of MPS takes a broader view of the production process, focusing on throughput, quality, energy and reliability, again providing guidance to production engineers and plant floor personnel. It is equally applicable to processes as well as equipment and can serve the process, hybrid/ batch and discrete industries. But similarly to the previous category, their reliability functionality is limited to predictive capabilities.

The first type of MPS is very focused on machine utilization and downtime minimization andis less holistic than the second category. The second category would benefit from an APM solution that complements its remaining production optimization functionality rather than being limited to PdM.

A variation of MPS are those industry-dedicated solutions that combine a data infrastructure with advanced analytics capabilities, including asset performance and PdM. These are offered as configurable solution development frameworks (e.g., XMPro iDTS) or as pre-packaged applications (e.g., C3.ai Reliability).

The most comprehensive APM solutions bring everything together, combining analytics, strategy and execution in a single environment. But with that depth comes complexity, cost and implementation challenges. These solutions contain all the elements of an APM solution and are primarily targeted at the large continuous process and other asset-intensive industries. As such, large ISVs and automation companies tend to dominate this space. For example, GE Digital, Aveva, AspenTech and Honeywell, etc. Often encompassing CMMS/EAM with APM functionality, they can be costly to acquire and complex to implement and maintain. Many users do not take advantage of all their many features or, in some cases, don't really need them or have the staff to support them.

Think of it like Excel. How many of its 450+ functions do we typically use? Amazingly, despite its plethora of features, most of these solutions offer only PdM capabilities and furthermore, one may have to choose the algorithms to apply to the data. This means that users must have at least some data science background to configure the reliability portion of the system.

The bottom line is that this category of APM is a comprehensive tool designed for large-scale, complex needs. If your requirements are less extensive, you might consider other options. Or, if you do have substantial needs, you may be seeking a more user-friendly solution. The key is fit. Organizations need solutions that match their scale, complexity and capability, without adding unnecessary friction.

What to look for in an APM solution

The right APM approach balances capability with usability. There is a core set of APM solution capabilities . Note that these capabilities consist of both services and software. These major elements should be on the user's shortlist to screen potential vendors.

1. An effective APM vendor should help define optimal maintenance and inspection strategies. These services should be supported by a risk analysis tool.

2. The output of the risk analysis tool should directly inform how each asset is managed, from run-to-fail and routine maintenance to condition-based, predictive and prescriptive approaches. These approaches must also be configured for each asset in the CMMS/EAM system.

3. PdM and RXM should focus on the most critical assets first, scaling over time as needs evolve.

4. Configuration should be intuitive, without requiring data science expertise or manual selection of algorithms.

5. The solution should do that for the user automatically behind the scenes. The solution should be easy to configure, meaning no coding, with features like drag and drop, check boxes and options, fill-in-the-blank and more. Maintenance technicians and engineers should be able to use the software with minimal training effort.

6. A strong APM solution also includes a built-in FMEA library to support root cause analysis and resolution. The user should be able to add custom assets, failure modes, conditions and actions.

7. Integration is essential. The solution should easily integrate with popular CMMS/EAMs, historians, third-party CBM, inspection and rounds systems.

8. From there, insight must translate into action. Alerting, collaboration, analysis, reporting and work order triggering should be part of the workflow.

9. The solution should be able to run on-premises or run in the cloud in a software-as-a-service (SaaS) mode to provide deployment flexibility.

10. Pricing should reflect the ability to start small and then scale, meaning no large upfront license fees.

Pitfalls and challenges

Even with the right approach, implementation comes with challenges. There are five common pitfalls or obstacles frequently encountered in implementing APM.

The first is the lack of the right information infrastructure to collect, store and provide quality data to the APM solution. Despite their widespread use in the process industries where distributed control systems (DCS) come packaged with a historian, many hybrid/batch and discrete manufacturers lack historian functionality. MES/MOM, supervisory control and data acquisition (SCADA), and PLC- based control systems tend to have limited data storage capabilities. On-premise and cloud-based historians are widely available, enabling even the smallest manufacturers to manage production data cost effectively. IIoT and edge computing devices can easily integrate with this infrastructure.

The second obstacle is that many organizations do not adequately maintain their EAM/CMMS. The asset hierarchies in the EAM/CMMS need to properly align with the historian and control systems, as well as the financial ledger that manages asset amortization, procurement of spare parts and labor hour tracking. These systems need to be cleansed and updated for APM to work properly.

The third challenge is to avoid getting into an algorithm comparison between competing alternatives. While there are proprietary ML algorithms and well-known open-source ones, there are few people (i.e., PhD data scientists) who can determine the difference, and there is no standard for testing them. On a comparative basis, APM solutions in today's market offer very similar first principle models and machine learning algorithms. The real test is the ease of building and deploying the predictive functionality and ensuring it is accurate for a given operating context.

The fourth challenge is finding the right vendor with domain experience who really understands the principles, processes and practices of reliability and asset performance management. Many PdM products offered by analytics firms lack deep domain experience. Yes, they know how to make ML algorithms work with data, but as we have been discussing, APM is much more.

The fifth challenge is organizational readiness. Given APM's capabilities of PdM and RxM, how will the maintenance, inspection and operations work processes be impacted? What needs to change? What workforce skills need upgrading? Thus, there is a change management component that should not be overlooked or underestimated.

It is important to address the above before rushing off to try out a solution in a pilot, then later only to find out that the solution did not work as intended or that one cannot scale the solution. Users are encouraged to get outside help if needed.

Summary and conclusions

APM doesn't have to be complex to be powerful.

With the right approach, organizations can implement solutions that are scalable, intuitive and cost effective without compromising capability. The goal remains simple, connecting insight to action, reducing complexity and driving measurable improvements in reliability and performance.

For most organizations, the path forward isn't about adding more tools. It's about choosing the right ones, and making them work in rhythm with the business.

About the author

Joe Perino is an independent consultant and advisor focused on industrial transformation and operational excellence for the energy, process and manufacturing industries. Perino founded PERTEX in 2015 to help industrial organizations drive business results. He is actively involved with the Industrial Internet of Things (IIoT), DataOps, advanced analytics (AI/ML), cloud and edge computing, digital twins, robotic process automation and blockchain. Perino started his career as a process engineer in the refining, chemicals and pipeline sectors. He has worked for operating companies (Phillips Petro- leum, Diamond Shamrock, Northern Natural Gas) as well as automation and software firms (Emerson, Honeywell, Blue Yonder) and services firms (IBM, Schlumberger, CGI and DXC). Before going independent, Perino was a principal analyst for LNS Research, where he was the lead analyst for asset performance management, operational excellence, advanced analytics, autonomous operations and data management. He holds a BS in Chemical Engineering from the University of Notre Dame, an MS in Finance from the University of Houston-Clear Lake and has completed executive education programs at the Kellogg School of Management at Northwestern University and Harvard Business School.

Appendix

Preventive maintenance (PM) is activities performed on equipment that is subject to breakdown as part of an effort to ensure that equipment successfully delivers its function without interruption over a defined mission time.

Condition-based monitoring (CBM) is a technique that uses sensors, samples and data analysis to assess the health and performance of machinery or equipment. It listens for signals associated with known failure modes and is also configured to monitor process data such as load, speed, temperature, pressure and amperage to detect asset faults or failures.

Run-to-fail (RTF) maintenance is a strategy in which equipment and machinery are operated until they fail, at which point repairs or replacements are performed.

Reliability-centered maintenance (RCM) is a corporate-level maintenance strategy designed to optimize maintenance programs by establishing safe minimum levels of equipment upkeep. RCM emphasizes matching individual assets with the maintenance techniques most likely to deliver cost-effective outcomes.

Risk-based inspection (RBI) is an optimal maintenance business process used to examine equipment such as pressure vessels, heat exchangers and piping in industrial plants. RBI is a decision-making methodology for optimizing inspection plans. The RBI concept lies in that the risk of failure can be assessed in relation to a level that is acceptable, and inspection and repair used to ensure that the level of risk is below that acceptance limit.

Failure modes effects and analysis (FMEA) is a structured method of assessing the causes of asset failures and their effect on production, safety, cost and quality. FMEA are methodologies designed to identify potential failure modes for a product or process, assess the risk associated with those failure modes, rank the issues in terms of importance and identify and carry out corrective actions to address the most serious concerns.

Computerized maintenance management systems (CMMS) vs. enterprise asset management (EAM). Whereas a CMMS is used primarily to manage the maintenance of equipment and machinery, EAM takes a holistic view of the complete asset lifecycle management, which also includes planning, procurement, inventory, operations and disposal. It maintains information at every stage of the asset lifecycle.

Predictive maintenance (PdM) is maintenance activities based on the prediction of the future condition of an item estimated or calculated from a defined set of historic data and known future operational parameters.

Prescriptive maintenance (RXM) is an emerging approach to establishing a link between predictive analytics, maintenance strategies and decision making. Prescriptive maintenance aims to integrate advanced data analytics, machine learning, and knowledge-based systems with production planning and control (PPC) to optimize maintenance activities and overall production efficiency.

Artificial intelligence (AI) is the ability of machines to perform tasks that are typically associated with human intelligence, such as learning and problemsolving.

Machine learning (ML) is a branch of AI and computer science that uses data and algorithms to imitate how humans learn, gradually improving its accuracy. It's an umbrella term for solving problems for which the development of algorithms by human programmers would be cost-prohibitive, and instead, the problems are solved by helping machines 'discover' their 'own' algorithms.

There are several kinds of ML. Unsupervised learning analyzes a stream of data and finds patterns and makes predictions without any other guidance. Supervised learning requires a human to label the input data first, and comes in two main varieties: Classification (where the program must learn to predict what category the input belongs in) and Regression (where the program must deduce a numeric function based on numeric input). In reinforcement learning, the agent is rewarded for good responses and punished for bad ones. The agent learns to choose responses that are classified as "good". Transfer learning is when the knowledge gained from one problem is applied to a new problem. Deep learning uses artificial neural networks (ANNs) for all of these types of learning. ANNs are a branch of machine learning models that are built using principles of neuronal organization discovered by connectionism in the biological neural networks constituting animal brains.

Anomaly detection is the identification of rare items, events or observations that deviate significantly from the majority of the data and do not conform to a well-defined notion of normal behavior.

Statistics is the practice or science of collecting and analyzing numerical data in large quantities, especially for the purpose of inferring proportions in a whole from those in a representative sample. There are two main statistical methods:

1. Descriptive statistics, which summarize data from a sample using indexes such as the mean or standard deviation and…
2. Inferential statistics, which draw conclusions from data that are subject to random variation (e.g., observational errors, sampling variation).

What is the difference between statistics and machine learning? According to Professor Shahab D. Mohaghegh, at West Virginia University's Department of Petroleum and Natural Gas Engineering, a simple explanation is (paraphrasing): "With statistics, data is fitted to a mathematical model, while with machine learning, the data is the model."

Asset performance management (APM), as defined by Gartner, encompasses the capabilities of data capture, integration, visualization and analytics tied together for the explicit purpose of improving the reliability and availability of physical assets. APM includes the concepts of condition monitoring, predictive forecasting and reliability-centered maintenance.

DataOps, as defined by Gartner, is a collaborative data management practice focused on improving the communication, integration and automation of data flows between data managers and data consumers across an organization. The goal of DataOps is to deliver value faster by creating predictable delivery and change management of data, data models and related artifacts. DataOps uses technology to automate the design, deployment and management of data delivery with appropriate levels of governance and it uses metadata to improve the usability and value of data in a dynamic environment.

Generative AI (GAI) is artificial intelligence capable of generating text, images or other media, using generative models - a.k.a. large language models. Generative AI models learn the probabilistic patterns and structure of their input training data and then generate new data that has similar characteristics.

Generative AI was introduced in the 1960s in chatbots. But it was not until 2014, with the introduction of generative adversarial networks (GANs) — a type of machine learning algorithm — that generative AI could create convincingly authentic images, videos and audio of real people.

Causal AI (CAI) is an artificial intelligence system that can explain cause and effect. Causal AI technology is used by organizations to help explain decision-making and the causes of a decision.

What is the difference between generative and causal AI? While only predictive AI (using machine learning which is a form of correlative AI) can see into the future reliably, only causal AI can deterministically know the root cause of an issue and only generative AI can tailor recommendations and solutions to specific problems using advanced probabilistic algorithms.

State machine modeling is a mathematical model that groups all possible system occurrences, called states. Every possible state of a system is evaluated, showing all possible interactions between subjects and objects. A state machine is a behavior model. It consists of a finite number of states and is therefore also called a finite-state machine (FSM). The machine performs state transitions and produces outputs based on the current state and a given input.

Overall equipment effectiveness (OEE) is a measure of how well a manufacturing operation is utilized (facilities, time and material) compared to its full potential, during the periods when it is scheduled to run. It identifies the percentage of manufacturing time that is truly productive. An OEE of 100% means that only good parts are produced (100% quality), at the maximum speed (100% performance) and without interruption (100% availability).

OEE = Availability x Performance x Quality, or...

OEE = (Production Time / Potential Production Time) x (Actual Output / Theoretical Output) x (Good Unit Output / Actual Output)

Supervisory control and data acquisition (SCADA) is a control system architecture comprising computers, networked data communications, and graphical user interfaces for high-level supervision of machines and processes.

About Octave

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