# How to improve Overall Equipment Effectiveness (OEE) and utilization (TEEP) via digitalized “smart” process automation

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## Abstract

This technical article explores the advantages and disadvantages of a range of maintenance strategies, the benefits of predictive and prescriptive approaches and highlights how Heartbeat Technology functionalities can help process plants by impacting their Overall Equipment Effectiveness as well as utilization rate. It also shows how better control and management of measurement accuracy enables production companies to minimize the risk in critical processes while reducing operations costs and financial exposure.

## Introduction

It is a common understanding in production facilities that assets must be properly maintained to maximize productivity. This is generally monitored through a well-known metric, Overall Equipment Effectiveness (OEE), where maintenance splits between reactive and preventive activities. In addition, plant effectiveness is monitored through the Total Effective Equipment Performance (TEEP), which considers the scheduled and planned downtime, i.e., yearly shutdowns.

From a high-level, the main challenge for maintenance is to positively impact the OEE and TEEP by reducing downtimes as much as possible while still ensuring asset reliability. This means reducing the maintenance operation interactions to free up needed time for effective production. Simply said but can be difficult to achieve, as those two objectives contradict each other.

Reducing the amount of maintenance exposes the risk of failure in a relatively short-term, compromising up-time and increasing cost. On the other hand, increasing maintenance effort will certainly reduce asset failures but will also compromise up-time and thus degrade productivity as production interruptions are required to perform the planned maintenance interventions.

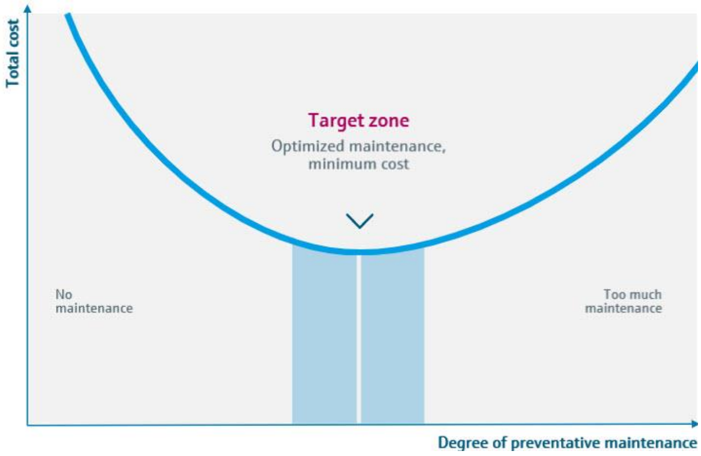

**Figure 1: Optimum maintenance effort**

It is obvious that no perfect solution is available, but the target zone between too much maintenance and too little maintenance can be reached. As shown in Figure 1, the target zone is an optimal trade-off in maintenance effort that lowers the induced costs, i.e., operational costs for maintenance and costs for production loss.

Even though the logic is well known, it remains a daily challenge; but is that all?

Unfortunately, not. Some might even say that this is the tip of the iceberg. This is because only an “asset perspective” is considered, ignoring the role of measuring devices. The common understanding is generally, “measuring devices are normally not the source of the problem”. Measuring devices have the specificity to be at the same time a device like any other that requires maintenance but are also the “eyes and the ears” of the process. What is the consequence if the information they deliver to the “brain” is not reliable? In other words: what is the impact of measurement accuracy on plant performance? Obviously, it has a significant impact. However, an inaccurate measurement is often not visible at first glance and might not be the primary focus of the plant operator.

This technical article aims to demonstrate the importance of measurement accuracy and selection of the appropriate maintenance strategy and their impact on the overall plant performance.

Measuring devices must benefit from the appropriate maintenance strategy, but they can also offer more possibilities thanks to the now available innovations, such as Endress+Hauser’s Heartbeat Technology functionality. The technical article “From field device diagnostics to process and plant monitoring [1]” explains these functionalities and how they can provide value in operations.

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[1] H.-J. Fröhlich, D. Persson and U. Kaiser, “From field device diagnostics to process and plant monitoring: How modern process sensors contribute to process knowledge and plant safety,” Endress+Hauser, 08/2021

The following will show how measurement (in)accuracy generates costs and how those costs are hidden. The traditional and newly available maintenance strategies will be explained and most importantly, defined on when to use each one. Finally, the positive impact on the OEE and TEEP will be demonstrated through a real-life case.

## What is the impact of measurement accuracy on plant performance?

The accuracy of measurement devices has a direct impact on the decision process behind the measurement. Not only will an inaccurate measurement affect the process control as such, but it will also have a direct financial impact.

First, it is important to understand that it is all about measurement accuracy and not solely measuring device drift. Indeed, a measurement device can possibly drift but that’s by far not the only root cause for inaccurate measurements. Measurement accuracy is also affected by other factors such as ambient temperature and vibrations as well as also process conditions like steam hammers, corrosion, build up, abrasion, cavitation, stability, homogeneity and in some cases the aging of meters, e.g., pH, conductivity, gamma sources, optical devices, mechanical wear, etc.

At the end of the day, the only attempt to fight measurement inaccuracies resides in an appropriate calibration program. Periodic calibration is preventive maintenance (we’ll see later a more detailed description of all maintenance strategies) that **more often than expected fails in anticipating** metrological performance drop **but always succeeds in generating operational costs**.

But the worst comes with the challenge of undetected inaccuracies. For example, consider a ship loading (24.000 m$^3$) of product valued at 1.5 $/l. This equates to a cargo value of 36 Mio$. A measurement deviation of 0.25%, will cost either the purchaser or the seller 90 k$ per ship. Considering 300 ships per year, the cost raises to 27 Mio$ which is far beyond the operational cost to perform periodic calibrations. This 27 Mio$ represents the actual **cost of inaccuracies** for that example, but it’s important to note that regulations allow for transactions a maximum measurement deviation of +/-0.5%, which leads to a **financial exposure** of 180 k$ per ship and 54 Mio$ per year!

The cost of inaccuracies is generally difficult to evaluate as the measurement error at the exact time of the measurement is unknown, but the financial exposure helps to quantify in terms of risk to which extent a company is exposed to financial losses due to measurement inaccuracies.

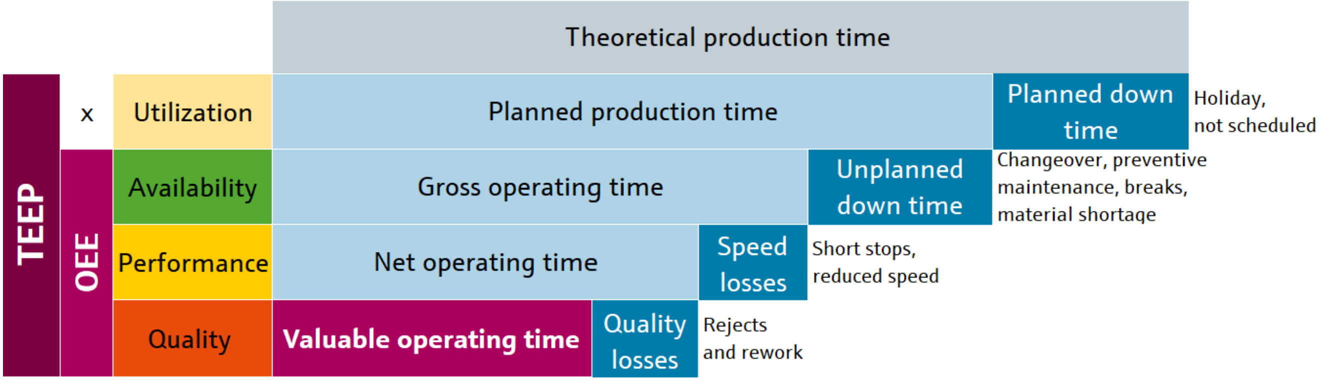
In some companies when commercial transactions are involved, such as refineries, these issues lead to discrepancies in accounting books between the two dealing companies. It results in another induced cost that could be called **accounting cost** and correspond to the man-hours required to reallocate the expenses in the books to clear up accounting discrepancies.

When this “accounting exercise” is performed, the cost of inaccuracies and the financial exposure is made tangible, but in most activities, it remains hidden. Simply said, the reason is that production facilities pay their bills and invoice what is sold. For instance, if 5% of extra energy has been consumed because of measurement inaccuracy, no one can spot it. This is “just” the margin that is gone.

Let’s make it clear here that the focus regarding measuring devices is related to operational cost, while the inaccuracy cost and the accounting cost exceed it by far. So, it might be time for plant operators to find a better strategy. The next concern would then be to measure the efficiency of that strategy. This can be done through established measures of productivity impact.

## Overall Equipment Effectiveness (OEE) and Total Effective Equipment Performance (TEEP)

The OEE and TEEP are widely used KPIs to measure effectiveness in a production plant. This metric provides insights into the true capacity of manufacturing operations. It takes into account both unexpected losses (as measured by OEE) and scheduled losses (as measured by utilization). Its computation is simple and well understandable (Figure 2).



OEE: Overall Equipment Effectiveness = Availability x Performance x Quality
TEEP: Total Effective Equipment Performance = Utilization x OEE

**Figure 2: Graphical representation of OEE and TEEP**

The figure above is illustrative, but what’s the linkage with measurement accuracy?

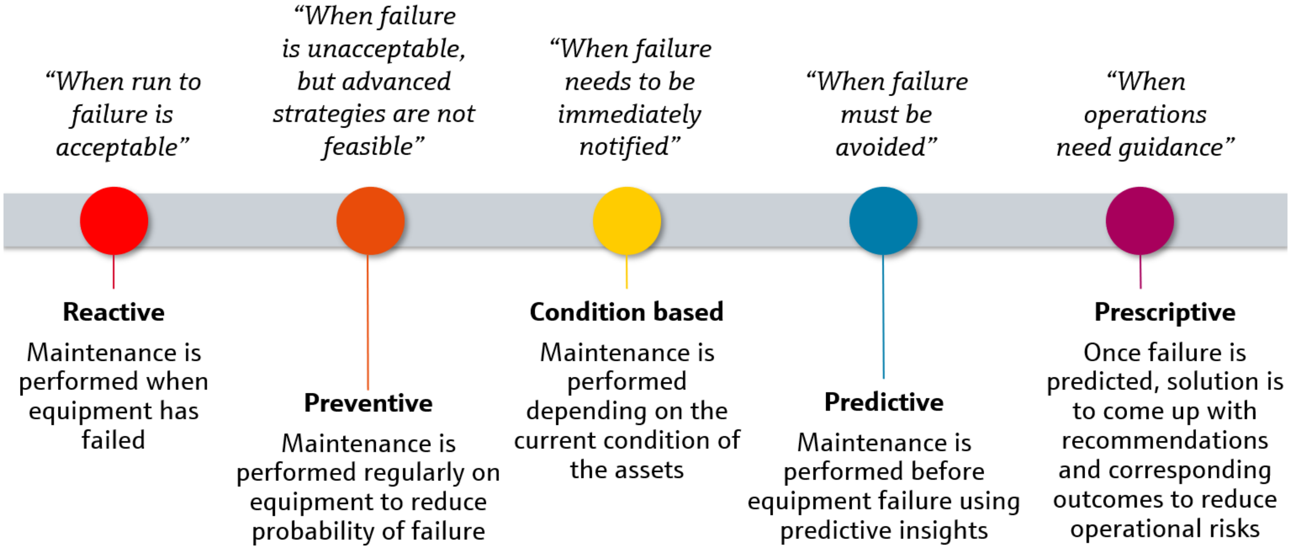
All four quantifiable components are affected by measurement performance, and with appropriate maintenance strategies and the help of embedded modern technology in the measuring devices, they improve significantly.

Indeed, proper planning and application of advanced calibration optimization methods improve **utilization**. The anticipation of failures thanks to the early warning or predictive information improves the **availability**. The increased confidence in measurements reduces the need for “on-demand verification”, reducing the related stops or reduced speed, thus improving the **performance**. Finally, better measurement accuracy keeps production under control by reducing its variability, raw material consumption and waste, thus improving **quality**.
In theory, it works, but the underlying preconditions relate to appropriate maintenance strategies in combination with advanced embedded technology.

## Maintenance strategies for optimal asset management

At first, it is crucial to remember that the choice of an appropriate **maintenance strategy is tied to the individual criticality of devices**. In essence, it is generally acceptable to let non-critical devices run to failure without any proactive maintenance, whereas it must be avoided for highly critical ones. Otherwise, the OEE will suffer from such a situation where either availability and/or performance and/or quality will be negatively affected. It looks like stating the obvious, but unfortunately, in practice, this simple principle is not a given.

The main takeaway here is to understand that there is **not one single maintenance strategy that prevails**, but the goal is to **determine the adequate strategy for each situation**. The definition and key usage of maintenance strategies are given in Figure 3:



*“When run to failure is acceptable”*

**Reactive**
Maintenance is performed when equipment has failed

*“When failure is unacceptable, but advanced strategies are not feasible”*

**Preventive**
Maintenance is performed regularly on equipment to reduce probability of failure

*“When failure needs to be immediately notified”*

**Condition based**
Maintenance is performed depending on the current condition of the assets

*“When failure must be avoided”*

**Predictive**
Maintenance is performed before equipment failure using predictive insights

*“When operations need guidance”*

**Prescriptive**
Once failure is predicted, solution is to come up with recommendations and corresponding outcomes to reduce operational risks

**Figure 3: Maintenance strategies landscape**

## Advantages, limitations, and applications of maintenance strategies

### Reactive maintenance

Reactive maintenance has the benefit to be one of the cheapest solutions as it doesn’t require any complex organization besides the spare parts stock, ordering process and obsolescence management. However, some issues do not get fixed immediately, and it might even take time to be noticed and require organizing operations on the fly.

This kind of strategy can’t fit high-critical devices as it would likely lead to downtime, quality, or safety issues, where the induced cost will tremendously exceed the savings of the maintenance effort. Consequently, this strategy can only apply to low-critical devices where malfunction won’t impact production and therefore, will not generate any downtime or slow down, as it can be fixed during idle time.

### Preventive maintenance

Preventive maintenance offers advantages over reactive strategies because of the proactive attempt to ‘prevent’ a failure. However, in between two periodic operations, the status of the device remains unknown. This is where the cost of inaccuracies defined earlier is applied. The measurement results are continuously provided, but their bias is usually undetectable till the next calibration.

As discussed earlier, keep in mind that the sources for biased measurements are numerous and not only related to device drift. In addition, most critical measuring devices are regularly calibrated, but those calibrations also introduce process and performance risks. This includes contamination in the process, human error and transportation/handling damage that will remain until the next calibration.

The main challenge in implementing an efficient preventive maintenance program resides in determining the appropriate frequency. When it comes to calibration, it is common to set a one-year fixed interval, but it is self-evident that there is no “gold number” and the interval applied blindly to all measuring situations has no chance to fit the purpose. Hence, an efficient calibration program will always include a sound determination of intervals. The truth is that it is rarely put into practice, but the consequences in terms of cost of inaccuracies are effectively there.

In essence, this strategy fits medium critical devices or generally more where the financial exposure remains acceptable. From the induced cost perspective, this strategy can improve significantly when the intervals are determined with a proven method that are taking into account influencing factors such as device type, aging, process influence, measurement criticality and expected metrological performance. To that extent, Endress+Hauser has effectively developed methods to determine such optimal intervals.

## Condition-based maintenance

Condition-based maintenance offers an improvement in over-reactive and preventive maintenance as it picks up the need for maintenance through real-time monitoring. Potentially, it offers a significant advantage to limit the cost of inaccuracies as the need for maintenance is immediately notified, thus reducing the reaction time for corrective action. In essence, one can see it as a reactive strategy with improved reaction time.

However, the reality is not as ideal as it seems. In practice, one can observe the following limitations:

Each alarm that is generated rarely gets fixed immediately as the process is running and can’t be interrupted anytime, so access to the zone might be difficult. Hence, even if the quality factor in OEE is impacted positively, it will in turn, negatively impact both availability and performance.

The other concern relates to the alarm itself. Even if the alarm is an early warning with respect to the previous two maintenance strategies, it can still be too late in the sense that the issue has already occurred. It then needs an unanticipated immediate fix. The opposite is also true, meaning that if the alarm comes too early, is too conservative or is even a “false positive” it leads to unnecessary process interruption.

With the increase of embedded diagnostics and thus the spread of condition monitoring, it becomes more and more common in practice to ignore the alarms as the operations are getting overwhelmed with them, since most of them relate to minor issues.

In conclusion, condition monitoring is of interest for high critical devices where immediate action is desirable and possible with acceptable reaction time, meaning when the cost of inaccuracies significantly exceeds the operational costs. However, it is crucial to consider the prerequisite to deploying such a solution as the necessary diagnostic technology embedded in the device, the communication protocol required for the field network, and the internal processes required to handle the alerts.

## Predictive maintenance

Predictive maintenance forecasts possible performance loss or potential malfunctions. It generally provides a predicted time, often called “remaining useful lifetime,” and a confidence attached to that prediction. This offers the advantage over previous strategies to anticipate failures, thus allowing efficient planning, reduction of financial exposure and reduction of product variability. Hence, it does positively impact OEE and TEEP as it increases quality, performance, availability and utilization.

Like condition-based maintenance, this strategy requires appropriate embedded technology in the device so that there are variables to monitor and build upon the prediction. In addition, it needs algorithms, often based on machine learning techniques, to perform the prediction. Hence the prediction performance is tight to the algorithm “quality” and should be understood that it delivers just a prediction, not certainty. This means that the predicted event is likely to happen but not certain to happen. A consequence is that a prediction that is associated with its confidence index to derive appropriate decisions with respect to the given context, like measurement criticality, will always be considered.

Predictive maintenance is based on embedded device technology but requires the appropriate field network. In addition, there is a need for computing power to run the algorithms, often requiring distributed IT architectures leading to data integrity and security considerations. Finally, the decision-making process and the operational process must be in place to derive an action (or not) from a prediction.

Predictive reliability offers a tremendous OEE and TEEP improvement potential, but the implementation effort is not negligible. Therefore, this is a strategy that fits high critical devices where financial exposure is high or when the production is at a bottleneck and requires capacity improvement. It is also advised to be considered when a measurement is related to safety or regulatory concerns.

### Prescriptive maintenance

Prescriptive maintenance is based on predictions but offers additional recommendations on what needs to be fixed or how to fix it. This allows companies to benefit from the advantages of the predictive strategy with improved operational efficiency. To a certain extent, it can be seen as a precious ally against skill scarcity and can ensure that the right actions are taken, at the right time.

Since the prescriptive maintenance is based on prediction, all previously made comments are also applicable. Even if the decision-making process appears to be simplified as delegated to the algorithm, the operational process must be well-defined and deployed to ensure the effectiveness of the corrective actions.

In some cases, the operational process is also automated, like automatic pipe cleaning with the appropriate cleaning agent, but brings additional constraints in terms of IT integration and system validation.

For predictive maintenance, prescriptive strategy is suited for highly critical measurements, where consequences span beyond the device itself. The potential for productivity gain can be very high but the efforts to deploy such a solution should be well evaluated. It has the potential to be a game changer, not just a slight improvement.

## Productivity impact analysis

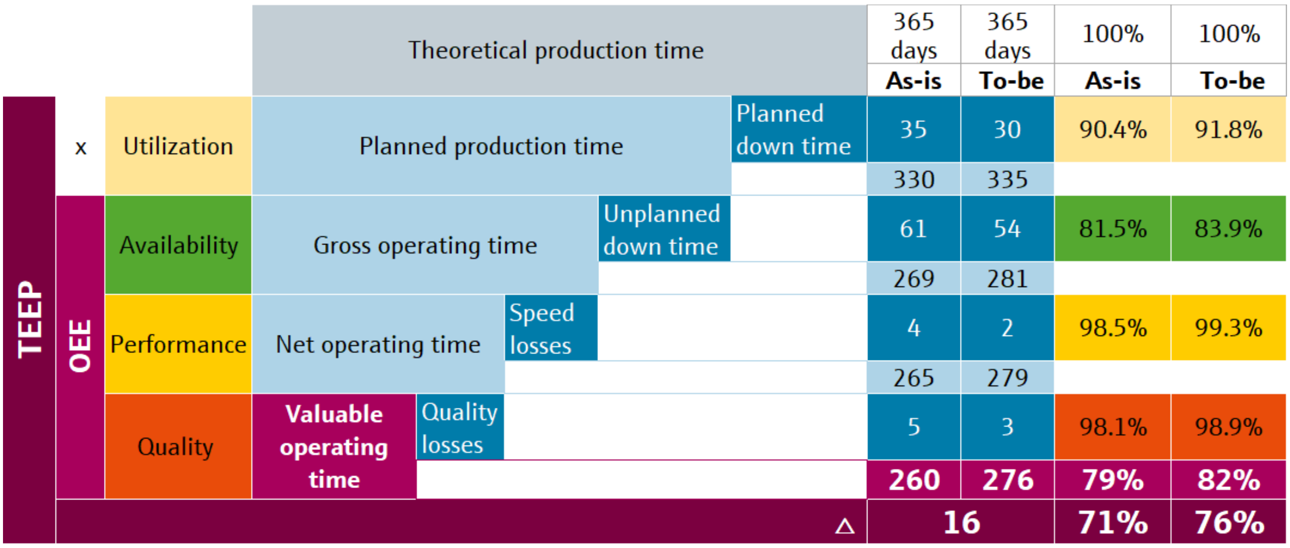
Although the theoretical explanation of different maintenance strategies makes sense, to justify a project or investment, a quantifiable business case is required. One approach for a business case is evaluating the cost of inaccuracies, as shown in the example above with the ship loading. Another (complementary) approach is through the perspective of the OEE/TEEP model to evaluate the potential increase in “Valuable Operating Time.” Even though numbers are highly dependent on the industry, even on the plant considered, the below calculation method does apply.

For example, let us consider a typical mid-size chemical plant with 1000 instruments in operation, 500 of which are defined as critical and are subject to a preventative maintenance program. This program is made of:

- Verifications, carried out every 6 months, generating in total 1000 operations per year
- Calibrations, carried out once per year on 300 out of the 500 critical devices

The plant runs 24/7, with a valuable operating time of 260 days. The yearly planned shutdown accounts for 35 days, affecting the utilization rate (TEEP). On top, 70 days account for unplanned downtime, speed losses and quality losses affecting the OEE.

By applying diverse maintenance strategies, ranging from reactive over condition-based to predictive, it is demonstrated that the valuable operating time can be increased by 16 days over the course of one year, as illustrated in Figure 4.



| | | | | 365 days | 365 days | 100% | 100% |
|---|---|---|---|---|---|---|---|
| | | Theoretical production time | | As-is | To-be | As-is | To-be |
| TEEP | x Utilization | Planned production time | Planned down time | 35 | 30 | 90.4% | 91.8% |
| | | | | 330 | 335 | | |
| OEE | Availability | Gross operating time | Unplanned down time | 61 | 54 | 81.5% | 83.9% |
| | | | | 269 | 281 | | |
| | Performance | Net operating time | Speed losses | 4 | 2 | 98.5% | 99.3% |
| | | | | 265 | 279 | | |
| | Quality | Valuable operating time | Quality losses | 5 | 3 | 98.1% | 98.9% |
| | | | | **260** | **276** | **79%** | **82%** |
| | | | △ | **16** | | **71%** | **76%** |

**Figure 4: Chemical plant – productivity impact analysis**

To emphasize these significant savings, let’s break down the calculation into each relevant OEE/TEEP-variable to understand the impact of optimized maintenance strategies.

### Utilization

The overall time spent on instrumentation maintenance (mainly for calibrations) during the yearly plant shutdown amounts to 30% of the overall shutdown time. If 8 service engineers execute calibrations on 300 devices full time, it takes them 10 days to complete the necessary work. By applying calibration optimization activities, significant savings get achieved through better control of the device’s metrological performance. The selection of appropriate asset criticality and measurement tolerance settings, in combination with scientifically proven calculations, allows for determining the ideal calibration interval for each field device. To reduce the calibration effort by 50%, reducing the planned downtime needed for calibrations to 5 days will lead to savings of 15% of the total yearly plant shutdown time, from 35 to 30 days.

### Availability

Optimized maintenance strategies have a significant impact on availability by drastically reducing reactive maintenance activities. In the current situation, there have been 61 days of unplanned downtime caused by multiple reasons. Out of these 61 days, 10 days are attributed to instrument failures with the need for device diagnostics and troubleshooting, leading to repair or replacement and causing an unplanned shutdown.

The implementation of a condition-based and predictive maintenance system, combined with device diagnostics and remedy information, contributes to a reduction in the time needed to carry out corrective maintenance activities. Although condition-based and predictive maintenance systems also trigger a certain amount of new unplanned activities, the unplanned downtime caused by instruments is reduced by 70%, which equals 7 days out of the initial 10 days. Consequently, the overall unplanned downtime decreases from 61 days to 54 days.

### Speed losses

Speed losses correspond with production slowdowns for unplanned fixes but do not cause an interruption in production. For example, this is when issues with production performance have been found and require an investigation. This represents a total of 4 days per year. When instrumentation performance is questioned, devices are taken out of the process for checks and on-demand calibrations. This has been the case for 12 field instruments in one year, resulting in 2 days of work with the devices out of operation. Regular calibration optimization activities, combined with the application of predictive reliability algorithms enabled through smart instrumentation, eliminate these suspicions. As the instrumentation performance is confirmed with confidence, the cost of inaccuracies is limited. Therefore, the speed losses can be reduced by 50%, from 4 days to 2 days.

### Quality losses

Quality losses correspond to non-satisfactory products that must be either reworked or dropped off. In both cases, this leads to the corresponding amount of production time lost, which in our example represents 5 days. As shown during the introduction, measurement inaccuracies have a direct impact on quality losses on top of raw material and energy consumption. Focusing solely on quality losses due to inaccurate measurements, this accounts for 3 days. With the application of calibration optimization combined with predictive reliability measures, 2 out of the 3 days can be saved. This leads to an overall reduction in quality losses from 5 days to 3 days over the course of one year.

### Other relevant savings

On a side note, this productivity impact analysis based on the OEE/TEEP model does not consider the savings in working hours for planned and unplanned maintenance activities. As maintenance staff does not have to carry out the original amount of service work, this directly results in OPEX savings. In addition, OPEX can be reduced further through smart instrumentation, with verification functionality powered by Heartbeat Technology. Verification activities usually do not affect the availability of the instrumentation, as it is not required to remove the field device from operations. On top, the instrument's performance is not compromised, as the primary measurement task of the device is not affected by the ongoing verification, so there is no impact on the operational equipment effectiveness. However, field devices with Heartbeat Technology decrease the time needed to carry out verification activities by 67% compared to "non-smart" devices. In our example with 1000 verifications done over the course of one year, this amounts to 20 days' worth of work, further impacting operational expenditures.

## Summary

This article highlights how much measurement devices can significantly impact a plant's effectiveness through appropriate maintenance strategies, made possible thanks to advanced embedded technologies and state-of-the-art machine learning algorithms. To that extent, Endress+Hauser, as a leader in field instrumentation, has developed both through Heartbeat Technology, calibration interval optimization and predictive reliability from an artificial intelligence perspective.

Together it allows:

- Increase in planned production time due to reduced duration of planned downtimes, such as deploying a predictive maintenance strategy or if condition-based maintenance reduces the number of operations required during the shutdown, thus reducing the time required

- Increase in the gross operating time due to significant less unplanned downtimes, i.e., failures are predicted or early detected and therefore are avoided due to predictive or condition-based approaches
- Increase the net operating time by reducing the time spent on potential root causes for the speed losses, i.e., the time required to investigate root cause is reduced, as measuring devices are permanently under control. Thanks to automated prescriptions this might even be enhanced further
- Increase in production time, as inaccuracies will be prevented, i.e., ensuring measurement performance by predictive or condition-based approaches guarantee production stability, avoiding waste or rework

The key message is that measurement inaccuracy leads to costs that are often hidden but real. Having measurement under control requires implementing changes, starting with a better understanding of the measuring device's impact.

To make it happen it requires 3 major components:

- Technology
- Process
- People

The appropriate technology, such as Heartbeat Technology and related algorithms, IT infrastructure and field network to extract information from data. The right processes must be in place to transform information into effective actions. Finally, access to the required expertise and know-how to apply the outcomes of the technology and process is the key to success.