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Deploying the Time-in-State Metric in Real-time to Improve Process Performance

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ABSTRACT

This whitepaper explains how to implement a management and control methodology on the plant floor in real-time to improve the Time-in-State Metric (TISM). The whitepaper also explains what tools the operators will require to guide them in making the most effective decisions and how these tools need to be maintained and calibrated.

The design of tools to monitor and manage Time-in-State Metrics is based on the principles of interpretation of data leading to valuable information, and the design of high-performance HMI systems. Also important to the design and operation of tools for TISM is the understanding of methodologies to be employed when the process is out-of-optimum and needs to be brought back to ideal state. The design of these systems in the process industry needs to take into account that changes to operating parameters can take some time to manifest. Multiple adjustments made to rectify an out-of-optimum situation should not be made in quick succession.

Finally a few suggested artifacts from recent projects will be presented to illustrate the use of TISM data by different roles in the process manufacturing plant. This will show how information is aggregated according to the ISA-95 equipment hierarchy and the level of responsibility interest area of the user accessing the information.

INTRODUCTION

The first whitepaper in this series introduced the Time-in-State Metric (TISM) and provided an explanation of how the metric is used in practice. The document also illustrated how the Time-in-State Metric establishes a platform for proactive management of conditions having a negative impact on efficiency.

The Time-in-State Metric implementation methodology has a strong emphasis on the human element and specifically on decision-making within the operating environment. The effectiveness of decision-making is a function of experience, understanding and interpretation of production process conditions.

Associative learning plays a significant role in building a person's perception and opinion of a specific subject. The correctness of learning is influenced by the complexity of the system the person interacts with. The multi-dimensionality and size of continuous processes are in most cases too much for humans to easily comprehend. Consequently, humans visualize patterns and simple rules to reduce complexity but, in doing so, inaccuracy and bias are introduced.

To mitigate the complexity and to reduce biased decision-making as much as possible plant operators can be assisted by real-time tools to guide them in decision-making. These tools need to be simple and to provide actions and steps the operator can follow in the event the process moves outside of the ideal state.

The tools also need to be flexible so that the actions and steps can be adjusted or calibrated easily by the process experts once new learning becomes apparent.

PRINCIPLES

Decision-making environment

Information is defined as communicated or received useful knowledge concerning a particular fact or circumstance. This implies that data describing the circumstance, event or condition has been interpreted and processed. This reasoning also implies that in the absence of reliable interpretation, production process data is nothing more than noise.

It is therefore important to convert production process data into confirmed, validated and de-biased information. In the context of limited experience at the operational level, the importance of making interpreted and unbiased information available is highlighted.

Understanding what factors contribute to process variance, what the operational decision-making requirements are, and linking different operating conditions to performance levels provides a baseline to motivate development and improve technology selection.

Operator Graphics Design

People can easily be distracted by color and movement. Flashing colors in abundance become distractions and may cause operators to lose focus. According to *The High Performance HMI Handbook: A Comprehensive Guide to Designing, Implementing and Maintaining Effective HMIs for Industrial Plant Operations*, visualization needs clarity, consistency and to provide feedback. These three principles are detailed below as they apply to Time-in-State Metric (TISM) visualization.

Clarity

- Graphics are easy to read and intuitively understandable
- Graphics show the process state and conditions clearly
- Graphics do not contain unnecessary detail and clutter
- Graphics convey relevant information, not just data
- Information has prominence based on relative importance
- Indications of abnormal situations are clear, prominent and consistently distinguishable

Consistency

- Graphic functions are standardized, intuitive, straightforward and involve minimum keystrokes or pointer manipulations
- The HMI is set up for navigation in a logical, hierarchical and performance-oriented manner

Feedback

- Graphic elements must behave and function consistently in all graphics and all situations
- Important actions with significant consequences will have confirmation mechanisms to avoid inadvertent activation
- Design principles will be used to minimize user fatigue as graphics are used constantly

STATE CHANGE CHALLENGES IN CONTINUOUS PROCESSES

Inherent delays in response to change

Unlike discrete processes, the effect of changing one or more variable set-points in a continuous process may not be immediately apparent. Cycle time, residence time, parallel-processing and other factors can delay changes in process conditions. Depending on the specific process, the effect of changes to a variable set-point may only become apparent within the process after two minutes or two days. In addition, due to the complexity of the process, the time for a process change to have an effect often varies as a result of other process conditions and cannot be consistently predicted.

Operators, when confronted with these indeterminate delays, often get impatient and make further changes to the same or other variables in an attempt to rectify a specific situation. These hasty (in relation to actual process response) changes more often than not result in more severe process condition fluctuations or even out-of-control processes.

Any tools provided to the operator need to take the process response-time into account when providing the operator with action steps to maintain or return a process to the ideal state.

Effects of interrelated variables

Continuous processes are affected by any number of variables (or Key Influencing Factors, also called KIFs). A set-point change to one variable will more often than not result in condition changes, not only to that specific variable, but also to other process variables. A small change in one variable may result in a small or large step change in another, depending on the specific process. Deep process understanding is required to identify when step changes are required and when incremental changes need to be applied to specific variables.

These inter-relationships are not easy to understand and as such operators often overcompensate or over adjust, resulting in fluctuating process conditions.

Due to the interrelationship of KIFs, any real-time tools made available to the operators to maintain or return a process to the ideal state need to take these relationships into account.

Inherent delay and interrelationships increase complexity

Figure 1 shows that the process realizes a Yield of around 70 percent when operating within the constraints defined in Figure 2. The dotted line in Figure 1 illustrates the Yield gradient – Yield is highest top right and lowest bottom left. Although Yield is highest top right it is not worthwhile, from an economical point of view, to operate in that range due to lower production volumes (Volumetric Flow is less than 160m3/h in this region).

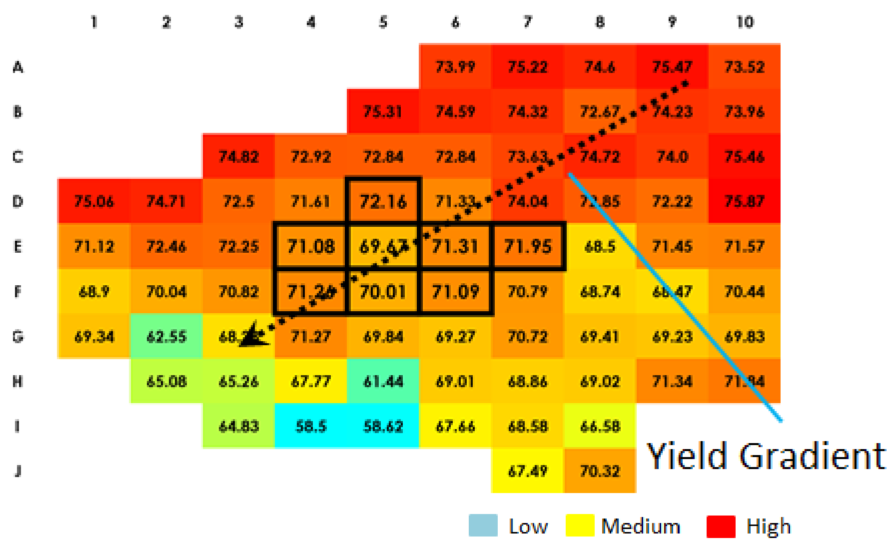


Figure 1: Yield map

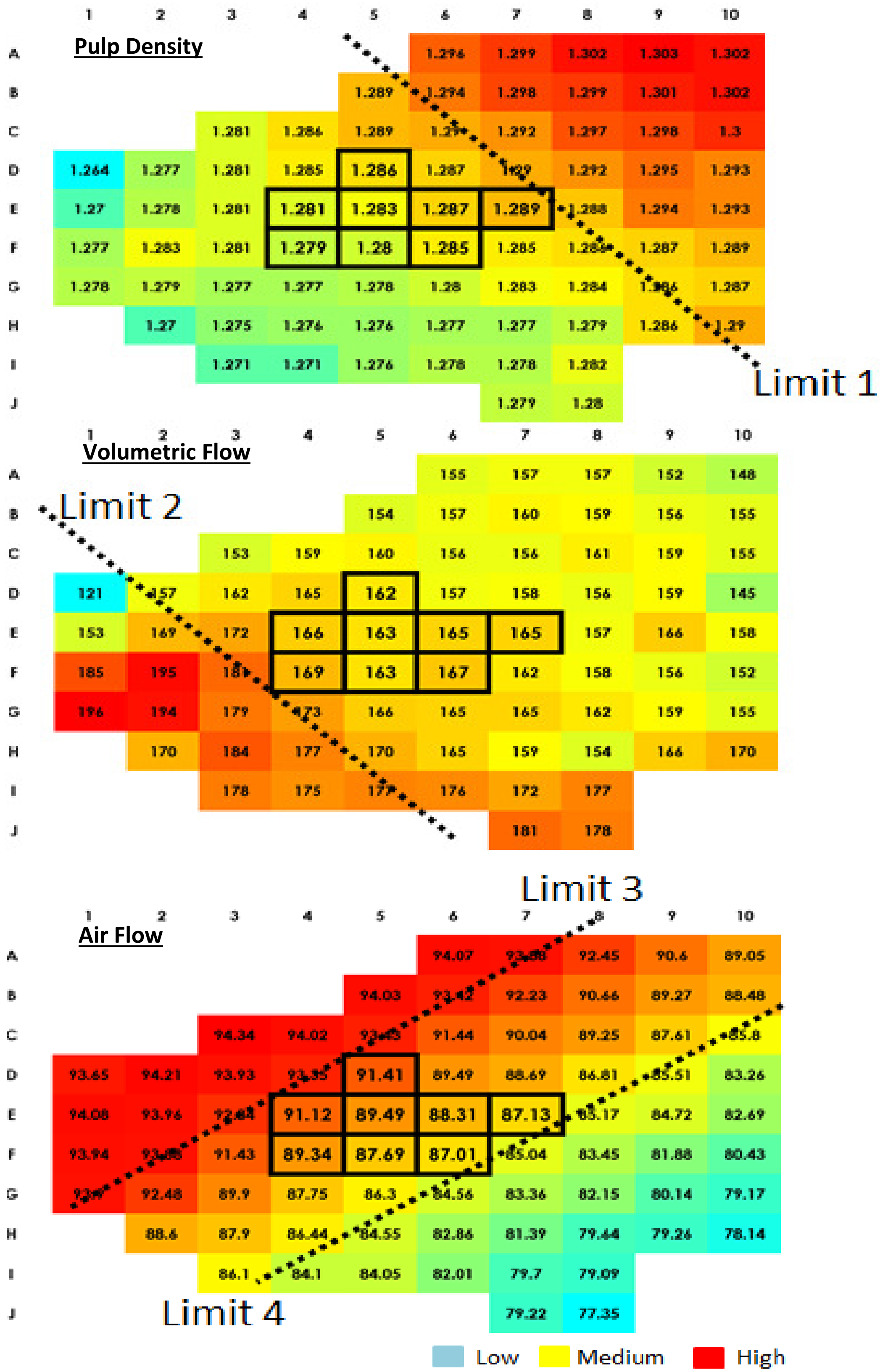


Figure 2: Ideal State limits for maximum yield

In the scenario shown in Figure 2, if the process has deteriorated such that it is in position H-6, the closest ideal state will be F-6. However, if the Airflow is increased in one step from 82.86 to 87.01, it can cause instability in the process as this is a huge change (24 percent of operating range of Airflow). In addition, the pulp density will not magically follow the Airflow immediately and may well reduce initially, leading to further unnecessary changes being made by the operator.

The best way to get to F-6 would be to step to G-6 first and give the process time to stabilize. Once all variables are constant in G-6 then the next step to F-6 can be made.

Any action steps guiding the operator in real-time need to take into account the possible adverse effects of step changes in set-points, as well as the response time of the process.

CHANGING STATE USING ACTION STEPS

Context sensitive operator action steps are defined for each of the Key Influencing Factors (KIFs). Action steps distinguish between conditions where a KIF is higher or lower than the target range. Action steps can be single or multiple actions or changes, including waiting time and condition evaluation actions. These actions need to be defined by the same team of process experts involved in the KIF workshops.

Each KIF is assigned a predefined weight by the Time-in-State model. The KIF weight is representative of the process' sensitivity to changes in the specific KIF.

Once the actions are implemented in real-time their effects can be monitored and evaluated to see if they have the required effect. Response times need to be evaluated to ensure adequacy. Process change actions need to be evaluated to ensure the required outcome without reducing process stability. In the event that action steps fail to deliver adequate results (such as process stability and returning to the ideal state), they need to be re-evaluated and changed or calibrated. This is an iterative process until such time as the action steps deliver the desired results.

A TIS model defines operating conditions that need to exist to realize process stability, predictability, effectiveness and efficiency. After implementation of the solution, process performance typically increases, provided that the correct guidance is provided to the operator. The TISM is used to:

- Quantify, in real-time, how close the process is operating to baseline state
- Quantify the proportion of time that the process met baseline conditions

The KIF mapping is repeated when a new level of Time-in-State achievement is reached to confirm assumptions and mental models, and so further potential improvements can be identified.

Things in the plant change periodically. New raw materials are introduced. New or reconditioned process equipment is installed to replace underperforming equipment or equipment requiring maintenance. New instruments to measure a process variable that may be a previously unmeasured KIF may be installed. When these changes occur, the process of KIF identification, performance mapping and action step definition should be repeated to ensure the most optimum performance of the process.

The operator’s actions/suggestions also need to be reviewed and updated iteratively, based on new information, new learning or when action steps prove to be inadequate.

VISUALIZATION USING REAL-TIME TOOLS

Visualization and feedback need to take place at different levels to ensure effective management of the TISM. At the lowest level or operator level, tools need to be provided that show the operator the status of the process conditions and if the various processes are operating in the ideal state. These tools should indicate the cause of deviations from the ideal state and need to provide operators with action steps to guide the rectification of the issues.

At the supervisor and manager level, real-time tools need to be provided that show the status of all the processes under their management so assistance can be provided to operators when required. At a more abstract level, TISM can be tracked and reported in real-time as well as periodically, to enable comparison with previous periods.

Operator-level Real-time implementation

The solution and its implementation can take different formats depending on customer preference, operator experience and technology applied. The display should be such that exceptions or out-of-ideal state processes (or Units) can be identified quickly and clearly as per the Operator Graphics Design principles.

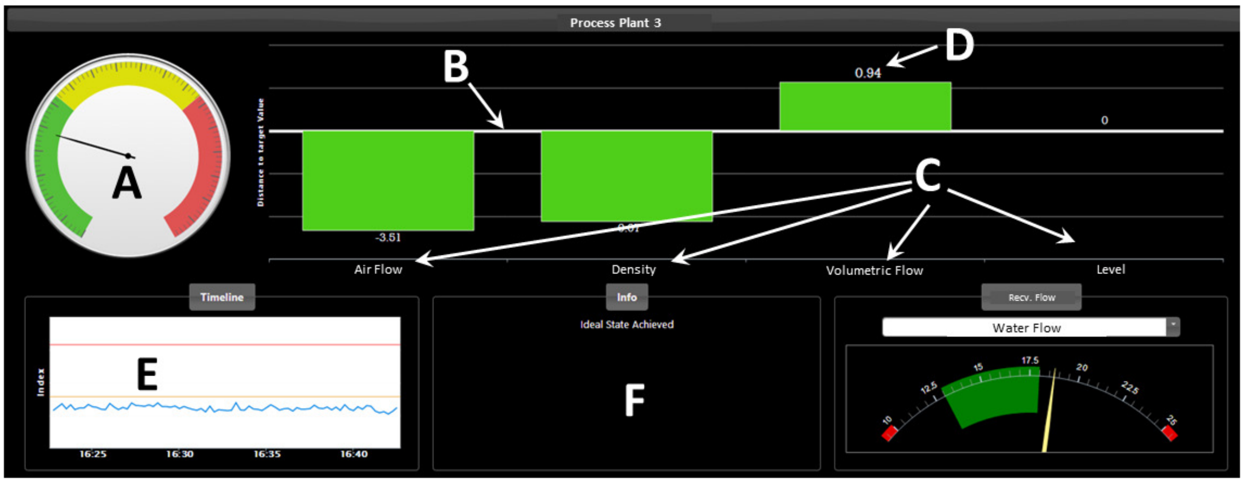
Figure 3 shows how ISA-95 Area or Production-Unit level information can be visualized to operators, supervisors or managers. The graphic shows that within the Mill Circuit Production Unit, the Primary Mill and Ball Mill Units are operating out of the defined ideal state but the rest of the Production Unit is operating within the ideal state. This information shows prominence based on relative importance as per the Operator Graphics Design principles and that the Primary Mill will get preference since it is further away from the ideal state.

The Performance Index Trend (below the Performance Index Dial) also shows that the Pebble Crusher 1 Unit, although currently operating within the ideal state, has not actually been controlled well in the previous period and needs close monitoring. This overview graphic conveys relevant information, not just data as per the Operator Graphics Design principles.

Figure 3: Operator Process Overview Screen

The tree-structure at the bottom left provides context to the graphic within the ISA-95 Area or Production Unit and can also be used as a navigation bar to move between Areas, Production Units and Units.

Figure 4 shows an example of how ISA-95 Unit-level process information can be presented to operators within the plant control room. This is a drill-down from Figure 3 and provides consistency in terms of the performance index display and history trend as per Operator Graphics Design principles.



A - Performance Index
B - Target Line
C - Key Influencing Factors
D - Deviation from target
E - Performance Index History
F - Feedback to Operational Staff (Knowledge base)

Figure 4: Real-time monitoring

The dial (top left-hand side) provides indication of how close the system is operating to the ideal state. The dial is referred to as the Performance Index for a specific process being monitored. While operating in the green range, the system is operating within the ideal state.

To the right of the dial at the top, the Key Process Influencing Factors (KIFs) are displayed as bar graphs. In this case the system has four KIFs. The dial will move outside the green range as soon as any one of the KIFs moves outside of the defined ideal state for the process. The bar for the related KIF will be colored red when moving out of the ideal state. The height of the bar combined with the color of the bar ensures that indications of abnormal situations are clear, prominent and consistently distinguishable from ideal-state conditions as per the Operator Graphics Design principles.

Context sensitive feedback as per the Operator Graphics Design principles is displayed in the Information box (bottom center) that relates to the current process conditions. This feedback will describe the action steps operational staff should take to rectify any deviation to ensure the system returns to the ideal state.

The line graph (bottom left) shows recent history of the Performance Index consistent with Figure 3 as per the Operator Graphics Design principles. This is important as it provides a trend that operators can interpret regarding the performance of the process over the recent past. This trend shows how close the process was operating to the ideal state during the period as well as provide early warning should the process be moving away from the ideal state even though still within acceptable process conditions.

The gauge (bottom right) contains selectable process parameters that provide additional, more detailed information regarding the selected variable. This is used with the Performance Index History trend when the trend indicates the process is moving away from the ideal state but none of the KIFs have exceeded the ideal-state defined limits or range.

Management-level visualization

From a real-time perspective, supervisors and managers will typically also use Figure 3 to monitor the state of the Area or Production Units under their control. The overview will provide them with information regarding the state of each of the Units as well as how the Unit has performed in the immediate past. If required, the supervisor or manager can drill down to look at the detail and monitor to ensure the operators take the appropriate actions.

Periodically the manager will also need to look at TISM compliance for the Production Units and Area under control. A typical report will look like Figure 5. The Performance Index is shown at the top. Ideal or baseline state is met when the Performance Index has a value less than the upper limit. This report shows data subsequent to a plant start-up. During interval A, the unit operated in baseline state for one percent of the time; the time in ideal state during interval B increased to 26 percent (the Performance Index was lower than the upper limit more often and for longer intervals). The condition of the Unit is therefore progressively moving closer to the baseline or ideal state.

In this example the Performance Index provides early warning of whether the start-up conditions are managed correctly or not. It also provides real-time feedback indicating which parameters are causing the unit to operate outside the baseline state.

The peaks and troughs observed on the Performance Index match the frequency of the Float Feed Density process measurement. The magnitude of change on Float Feed Density is amplified in the Performance Index. This is an example of how the model assigns different weight factors to parameters; Float Feed Density has a higher contribution (weight) compared to the parameter RoConc Vol Flow.

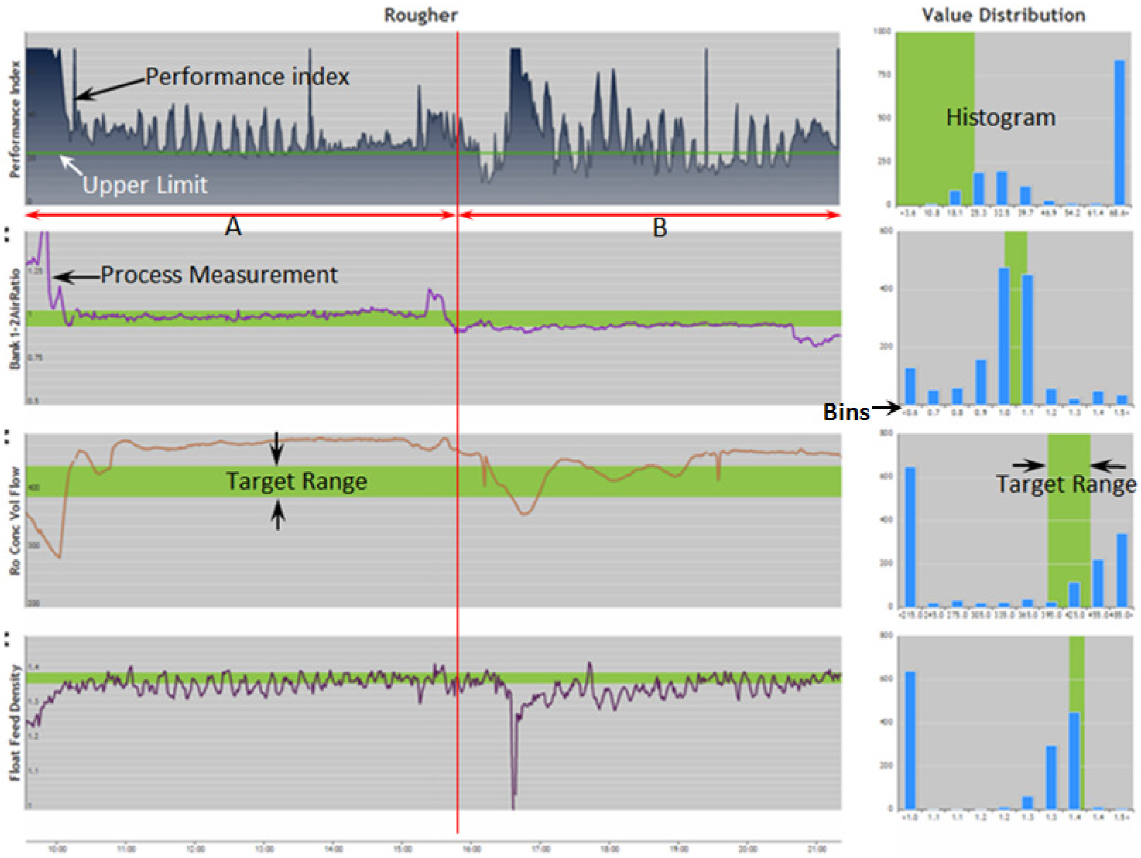


Figure 5: Time-in-State metric report

Figure 6 illustrates the Time-in-State Metric for two Production Units over an 18-week interval. In this example the percentage time in ideal state is calculated on a weekly basis. Management utilizes this information to allocate and focus efforts:

- Figure 6 shows that the Milling Unit is deteriorating. The detailed report shown in Figure 5 will typically be used to identify the conditions that are contributing toward this deterioration
- The Thickening Unit is improving and confirms that initiatives are contributing toward improvement

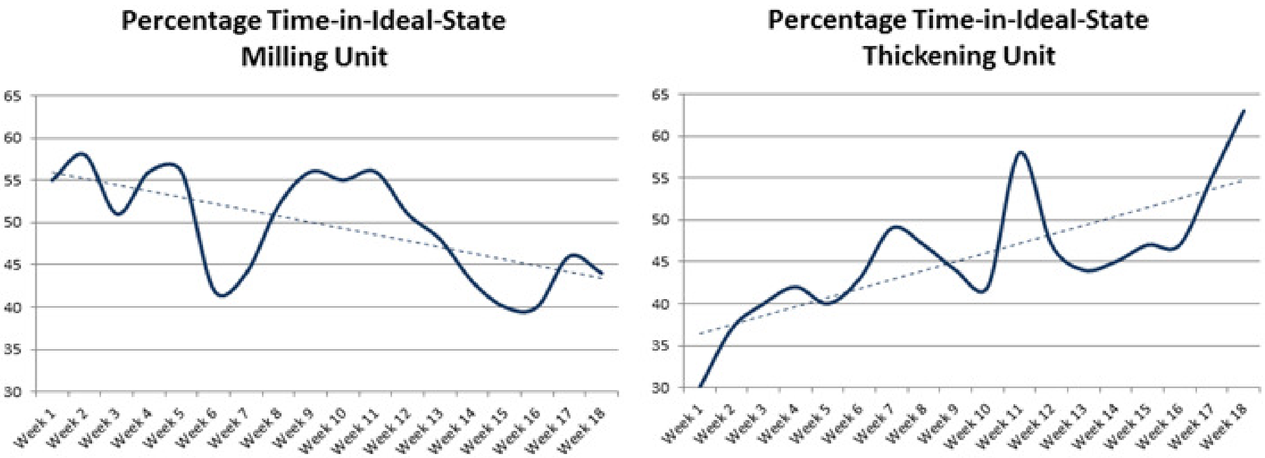


Figure 6: Percentage Time-in-State weekly aggregates

%Time-in-State for Area & Production Unit levels

Figure 7 illustrates how the Time-in-State Metric rolls up to state the %Time-in-State at Area or Production-unit level.

In this example the Production Unit consists of four Units: Primary Mill and Ball Mill, Cyclone and Pebble Crusher. At Unit level the height of each bar summarizes the percentage of time that the unit operated in the ideal state (per hour). For example, the Cyclone remained in ideal state all the time whereas the Ball Mill only reached ideal state during the last interval (19:00 interval).

At Production Unit or Area level, %TIS represents the time that all units contained within the Production Unit operated in ideal state at the same time. This can be seen for instance at the 15:00 interval where the individual Units ALL have a %TIS above zero, with the lowest two being just over 20 percent. However, at Production Unit level %TIS is zero as during this hour none of the Units within the Milling Circuit operated within Ideal State at the same time.

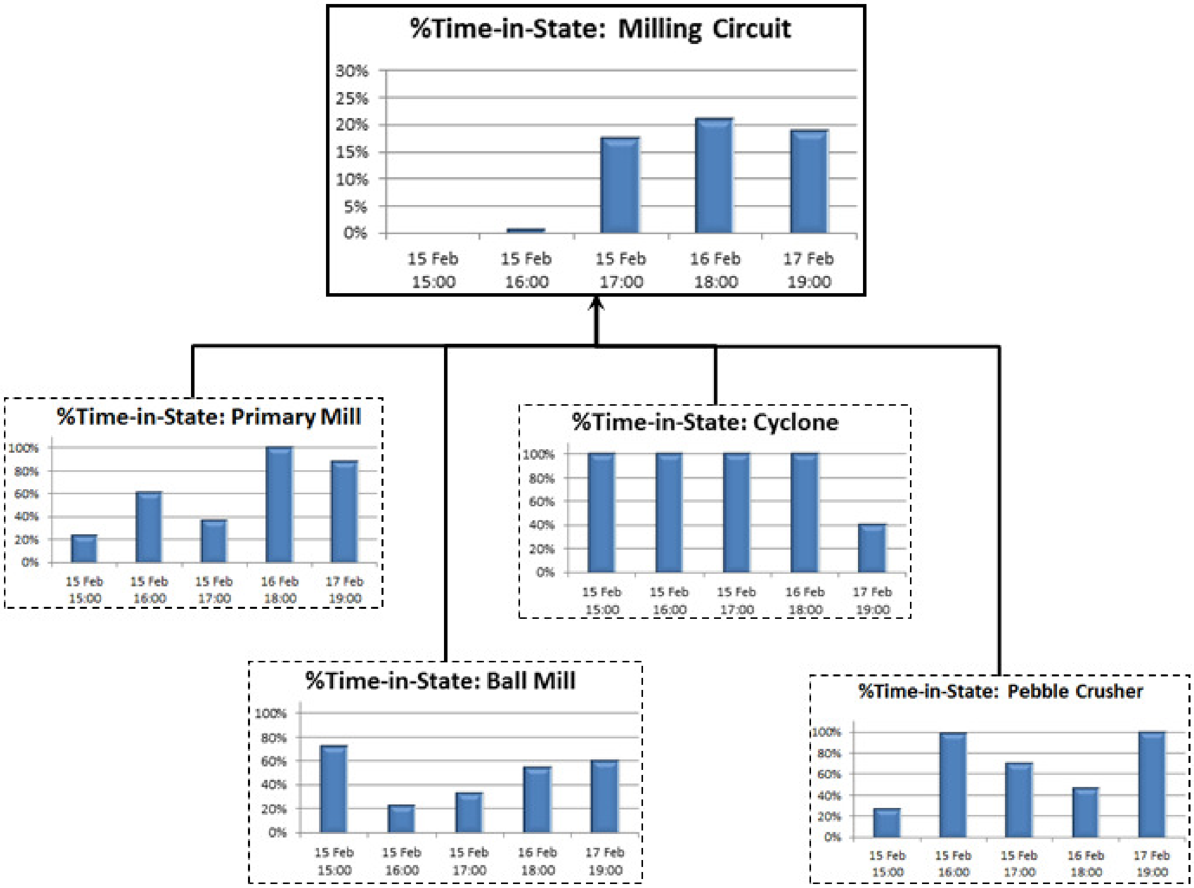


Figure 7: Summarizing the %Time-in-State per Production Unit

CONCLUSION

The health of process manufacturing operations is often difficult to quantify because measurements of quality, effectiveness and efficiency lag the process and are not normally available during operations. The Time-in-State Metric presents an easy-to-understand alternative to traditional measurements of process health.

Continuous production environments are characterized by the operator's need to simplify and understand complex interactions which are not generally visible to be measured directly. Successful operation depends on an accurate understanding by the operator of the interactions between complex variables. This must then be used to manipulate control settings to drive the process in the direction of optimal production.

The Time-in-State Metric provides real-time feedback of how interactions between measured variables (flow rate, grade, etc.) and operator tools (valve position, speed, etc.) affect process health. This gives the operator meaningful information which can be used to optimize production in an environment where the quality of final product and the effects of actions taken are not immediately apparent.

Finally, it has been shown that the Time-in-State Metric can be used to provide a common understanding of KPIs and their dependent KIFs for management and operations personnel. The ability to take a global perspective on the operation, and relate this to the instantaneous measurements available to production operations, is critical to the success of manufacturing processes.

The way the Time-in-State Metric is implemented in real-time at the plant level and at the reporting level to management also provides quantitative feedback about the effectiveness of the program as it progresses through its various implementation phases.

NEXT STEPS

Depending on the acceptance and uptake of the Time-in-State Metric concept within the MESA community, MESA will potentially be working on the generation of a TISM guidebook.

FURTHER READING

MESA provides whitepapers that provide additional descriptive information on metrics including:

- Time-in-State Management in the Process Industries, MESA Whitepaper #47 (2014)
- Time-in-State Metric Implementation Methodology, MESA Whitepaper #48 (2014)
- MESA Metrics Guidebook and Framework Second Edition (2011)
- ISA-95: The Enterprise-Plant Link to Achieve Adaptive Manufacturing, Whitepaper #16 (2005)
- ISA-95-Based Operations and KPI Metrics Assessment and Analysis, Whitepaper #24 (2007)

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