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Elevating Paper Quality and Production Efficiency with Enhanced Machine Direction Controls

Abstract:

This paper discusses a new machine direction (MD) control package, MD Optimizer. Paper and board industry are going through a change of generation, whilst mills are becoming more intelligent and autonomous. The new MD control package offers flexibility in connecting various variables, simplifying the process of linking manipulable and disturbance variables to controlled variables, and enabling real-time adjustments and optimizations. Moreover, traditional machine direction controls and advanced process controls (APC) can be integrated into a unified platform. This integration streamlines the management of the entire paper machine process, allowing for a holistic approach to control. The main advantage of using this modern control solution is the simplified commissioning phase and more accurate process modeling capabilities. Modern control solution is today complimented with self-service analytics leading to improved decision-making and fostering a culture of continuous improvement with also the non-technical staff. In the reference case we present starch optimization project with new generation APC-solution targeting to maintain the paper strength properties and optimizing them with machine controls embedded in Valmet DNA. Soft sensor algorithm correction with laboratory measurements means that the end-quality variables like SCT CD & Burst, that are not measurable by on-line analyzers can be estimated precisely in most situations.

Sensors and analyzers in Pulp and Paper processes generate vast quantities of data, but the sheer quantity of data does not help the users unless the data can be effectively analyzed. Efficient data analysis tools facilitate identification and correction of production and quality anomalies. Hence not only collection the data, but also analyzing the data is becoming vital daily activity.

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Introduction

Machine directional control forms the base for well performing paper machine, as it affects the overall end-quality of the paper products by stabilizing the system. MD control is challenging due to the nature of papermaking process. The process is nonlinear, time-varying and consisting of multiple parameters with complex interactions. Also, the objectives of papermaking are changing and often conflicting: maximize production rate while minimizing the costs of operation. To reach these objectives, advanced control solutions are needed.

It has been well documented that model predictive controllers (MPC) are well suited for MD control tasks [1, 2] and they have been the standard control method of the industry for the last few decades. This decades of development have enabled current MPC products to be more robust and offer more advanced functions. Even a minimal tuning for MD control solution usually results with a sufficiently performing system. Consequently, the focus of effort has shifted.

As the industry evolves toward greater efficiency, successful commissioning now requires not only high-performing products but also the agile configuration of control systems. This raises the topic of user experience (UX). It is the term that describes the interaction and satisfaction of users with a product or system. UX has been a crucial aspect of software development for a long time, and it has enabled some products to gain a competitive edge in the market. However, in the field of automation, UX has often been neglected in favor of short-term efficiency. But this is changing, as the traditional automation and software development converges more and more.

There has been some discussion of these aspects within the industry [3, 4]. Long lifecycles of paper machines have resulted in large number of legacy automation systems. These systems are often outdated and do not meet the current challenges. UX is a key factor in modernizing the control solutions since it can help make automation more user-friendly, efficient, and reliable. It requires understanding the user needs, expectations, and experiences, and designing solutions that answer to them.

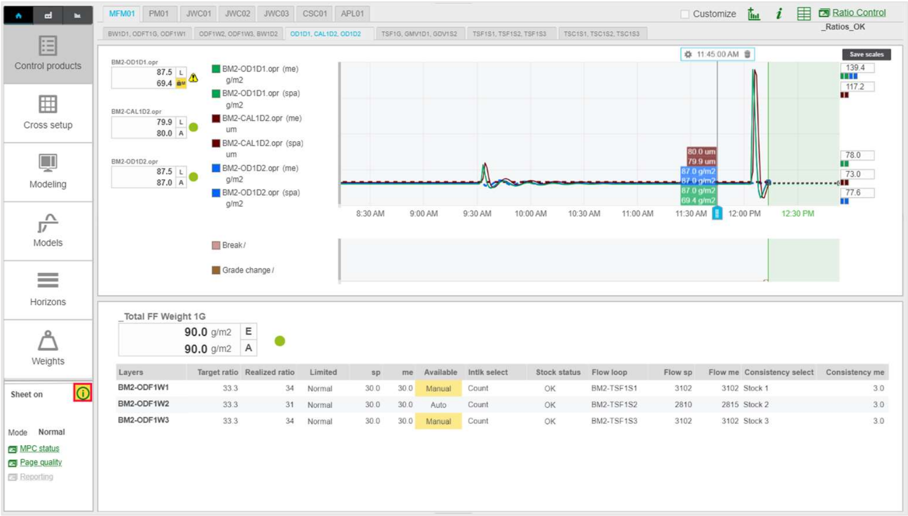
In this paper, we present a renewed MD control package. In the following sections, the user interface, modeling, control structure and workflow for the configuration are explained in more detail. The last section introduces performance results from a reference machine regarding starch-based end-strength control. We also highlight the transformative potential of self-service analytics, which empowers also non-technical staff to perform sophisticated data analyses, leading to improved decision-making and fostering a culture of continuous improvement.

THE RENEWED MD CONTROL PACKAGE

The interface is designed to be user-friendly and intuitive to use. It serves as a tool to implement and maintain machine directional controls. It is specifically designed for project engineers tasked with setting up the controls, as well as service and customer automation engineers responsible for upkeep.

The UI provides step-by-step guidance for setting up the controls during commissioning, as well as convenient built-in help boxes and default values that are automatically calculated and set according to the configuration. These features help to reduce commissioning time and errors in the setup.

The control page for multi stock ratio control is shown in Figure 1.



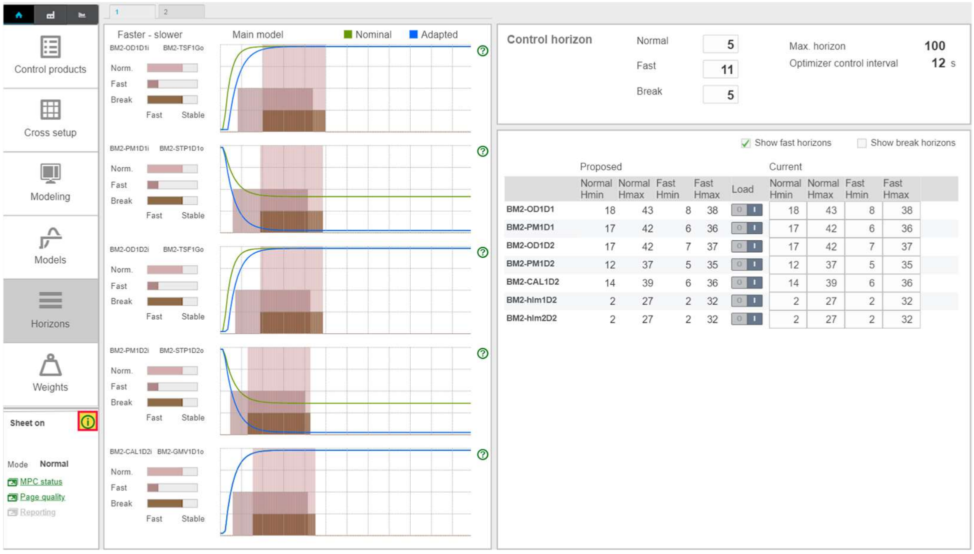
_Total FF Weight 1G
90.0 g/m2 E
90.0 g/m2 A

Layers	Target ratio	Realized ratio	Limited	sp	me	Available	Intlk select	Stock status	Flow loop	Flow sp	Flow me	Consistency select	Consistency me
BM2-ODF1W1	33.3	34	Normal	30.0	30.0	Manual	Count	OK	BM2-TSF1S1	3102	3102	Stock 1	3.0
BM2-ODF1W2	33.3	31	Normal	30.0	30.0	Auto	Count	OK	BM2-TSF1S2	2810	2815	Stock 2	3.0
BM2-ODF1W3	33.3	34	Normal	30.0	30.0	Manual	Count	OK	BM2-TSF1S3	3102	3102	Stock 3	3.0

Figure 1. Control products page

The top tab selection (highlighted MFM01) indicates the available control types and the bottom table shows web layer specific information.

The panel on the left of Figure 1 enables switching to different configuration views, which are self-explanatory. Control products show all the available controls, Cross setup allows defining the interactions between the variables. Modeling tab offers an automatic tool for modeling process models. Models tab shows all the model parameters, model adaptations and grade-dependent models. A detailed view of the models is presented later in the Modeling section. Below the Models, the user can configure the prediction and control horizons. An example view of the horizons tab is presented in Figure 2.



Control horizon
Normal 5
Fast 11
Break 5
Max. horizon 100
Optimizer control interval 12 s

☑ Show fast horizons ☐ Show break horizons

	Proposed					Current			
	Normal Hmin	Normal Hmax	Fast Hmin	Fast Hmax	Load	Normal Hmin	Normal Hmax	Fast Hmin	Fast Hmax
BM2-OD1D1	18	43	8	38		18	43	8	38
BM2-PM1D1	17	42	6	36		17	42	6	36
BM2-OD1D2	17	42	7	37		17	42	7	37
BM2-PM1D2	12	37	5	35		12	37	5	35
BM2-CAL1D2	14	39	6	36		14	39	6	36
BM2-hlm1D2	2	27	2	32		2	27	2	32
BM2-hlm2D2	2	27	2	32		2	27	2	32

Figure 2. Horizons tab

Horizons tab enables configuring the controlled variable -specific prediction horizons for normal, fast, and web break situations. Fast parameters are used when rapid changes are required for example during grade change. The control horizon can be changed, which affects the predictions and CPU requirements. The prediction horizons are moved according to adapted models. The last tab on the left panel, Weights, helps the user to select good weights and penalties for control by giving model-based suggestions of the values.

The next tabs include a page for machine setup, which contains break masks and a tool for defining delays between different parts of the machine. The last tab of the second panel includes the built-in simulator. The simulator allows running the controls against the simulated values. The third panel contains trends, which are presented in Figure 3.

Figure 3. Trend view

The controller trends can be configured dynamically within the tool and the user can select between different time scales, and customer or internal units for the trends. The next section focuses on the controller structure.

The controller structure

The MD control package is a platform that integrates four types of control variables: controlled variables (CV), manipulated variables (MV), advanced control variables (ADV), and advanced manipulated control variables (ADVMV). Additionally, external measurements (EXT) can be incorporated into the platform as inputs. A simplified block diagram of the structure is shown in Figure 4.

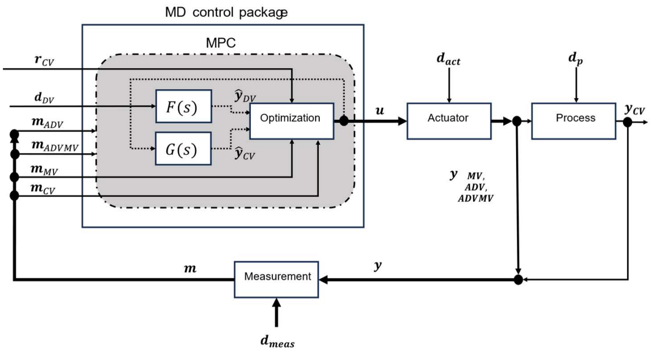


Figure 4. The controller structure

CVs are process output variables that are measured and regulated to achieve a desired setpoint or trajectory. MVs are process inputs that are adjusted to control the CVs. DVs are process inputs that are not controlled but have an impact on the CVs and need to be accounted for.

Besides the basic MPC variables MV, CV, and DV, the controller also includes ADV and ADVMV variables in its structure. ADVs are high-level control objectives that are achieved by manipulating ADVMVs, which are low-level actuators. ADVs and ADVMVs are used for quality control purposes that are not controlled by MPC, such as coordinated speed control or jet-to-wire control. To get a good control performance, modeling from MVs or DVs to CVs is required.

Modeling

The performance of MPC is dependent on the used process models. Identifying higher order models between MV and CV can prove to be quite difficult challenge in an interaction and disturbance heavy process. Typically, these higher order models are reduced to lower order models, which dynamics are easier to understand and lighter to compute [5]. Most common lower order models such as first order plus dead time (FOPDT) and second order plus dead time (SOPDT) are widely used in commercial control solutions. FOPDT models are most common due to their simplicity, but SOPDT models offer wider process modeling capabilities. These include modeling of process overshooting and non-minimum phase behavior in processes. Downside of using higher order than FOPDT models is that the frequency response data is needed for reliable parameter estimation.

The controller offers wide range of process model options between MV or DV and CV. It supports process models from first to up to six-degree models. The process models are formulated so that multiple first order sub models are used to form higher order models. This is useful when process model's detailed characteristics are needed. By combining the sub models, it is possible to form, for example, parallel second order model, feedback model with feedback ratio, integrating model or non-minimum phase model. Examples of these are presented in Figure 5.

To take advantage of the MPC, process model identification is needed. The controller includes a tool, which executes bump tests and calculates the model fit for a model.

As mentioned earlier, the process is nonlinear, meaning the identified linear models do not cover the whole operating area. To model the different operating points, model adaptions are in use. Alternative method for model identification has been studied and proposed.

Energy rich broadband signal allows the study of process in frequency domain. This is particularly important when identifying SOPDT models, which require frequency response data for parameter estimation. Figure 6 shows how MLBS excitation signal can be used in model parameter estimation. The frequency domain properties of the input and output signal can be used to calculate the empirical transfer function estimate (ETFE), which is the estimate of the system's frequency response. The periodicity of MLBS allows the averaging of the signal which makes the ETFE more robust. [7] This is crucial as ETFE serves as a data set for parameter estimation, which eventually is an optimization task. By fitting the desired model's frequency response to the calculated ETFE, estimation of the model parameters is acquired.

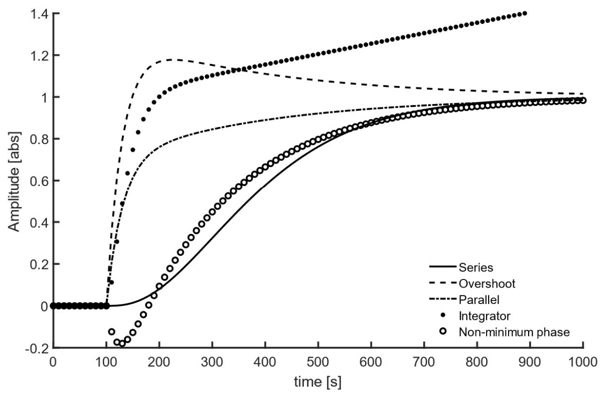


Figure 5. An example of available second order models

parameters is acquired.

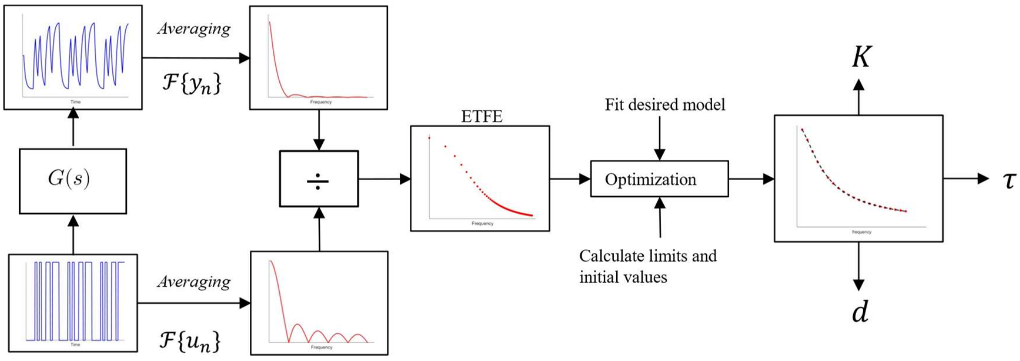


Figure 6. Workflow for parameter estimation using a MLBS signal

As mentioned, potential of the MLBS lies in its flexibility. Usage of low amplitude signal brings MD controls possibility for online model identification. This gives a better opportunity to estimate model parameters in different operating points and reduces the need for bump tests.

Besides flexibility in modeling, the controller has a scalable structure, which allows the user to add or remove variables controlled by MPC, other advanced control techniques, actuators or sensors depending on the needs and the capabilities of the process. To get better picture of how the controller structure allows freely to configure different kind of control set-ups, we explain the configuration process in the next section.

Example configuration case

We present a novel configuration of APC controls for a liner machine that requires simultaneous control of burst, SCT CD, S-Test, MD/CD Tensile ratio, CMT index and Starch amount on sizer. For this control the implementation consists of Soft Sensors (SS) where the process variables are used to estimate and predict the current value of a variable, in this case burst value.

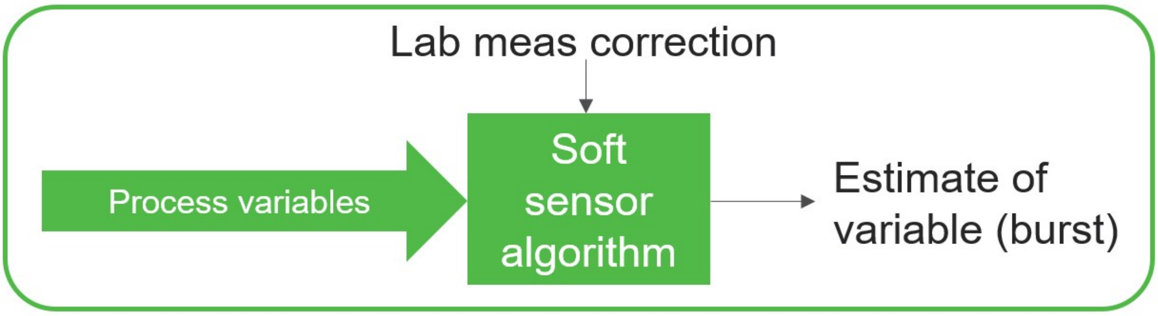
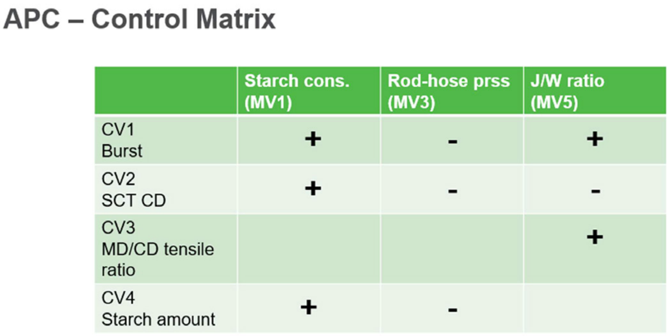


Figure 7. Example configuration of Soft Sensor for a burst control.

The SS is valuable when the controlled variables are note measurable by on-line analyzers but measured with laboratory measurements with a one sample per reel interval, which is too slow and few to build a control on top of. But when taking into account the selected process variables, for example "starch amount", "Jet to Wire(J/W) - ratio" and "Oven-dry weight", it is possible to model and estimate the value of the laboratory measurement in real time with the soft sensor and then control it with the APC. Estimation of the measurement is produced every minute.

The SS application consists of the laboratory measurements, processing variables, calculation, soft sensor output and offset correction based on laboratory results. For the SS to be able to deliver the control into the process a APC – Control Matrix is needed.



APC – Control Matrix

	Starch cons. (MV1)	Rod-hose prss (MV3)	J/W ratio (MV5)
CV1 Burst	+	-	+
CV2 SCT CD	+	-	-
CV3 MD/CD tensile ratio			+
CV4 Starch amount	+	-	

In the control matrix the relations between controlled variables and manipulated variables can be seen. The control has three ways to affect the CV's 1 to 4.

The APC-application also has several different capabilities to make it more user-friendly for the operators.

- Automatically handled sheet-break capabilities, meaning when a sheet break is occurring the APC will notice it and temporarily shut down itself. After the sheet-break has happened the APC will wait for another 5 minutes and then turns back on automatically.
- Automatically handled machine speed change, when the machine speed is changed the APC will temporarily shut itself down. After the speed change, APC will wait for another 10 minutes and returns back on automatically.
- Automatic grade change, when there is a grade change happening APC will turn itself off and give the control back to operator. After the grade change, there is a 10-minute waiting period where the operator can check new setting values for example starch consistency, rod-hose pressure and J/W-ratio.
- At any time, the operator can switch off any of the APC controls and do a manual change. This includes the starch consistency, rod-hose pressure and J/W-ratio. It is possible to set a new value and the turn the APC on.

PERFORMANCE

The performance of a modern, MPC-based APC control solution is presented in a real-life customer project in a linerboard machine. This project showcases the potential to increase the performance of a linerboard machine by stabilizing the process with a single platform, holistic approach for the APC controls.

In a board machine located in Europe, customer's target was to save starch with better end-strength management. The machine was producing board from Old Corrugated Container (OCC). The modern APC control approach for control consisted of the control matrix in figure 9. The baseline for the starch consumption on this machine line averaging for all grades dropped in total 5% after the APC had been installed. For the average European mill that has the price difference of OCC and starch in about 350€/ton this would mean starch savings of up to 35 000€/month, the principle is visualized in Figure 10.

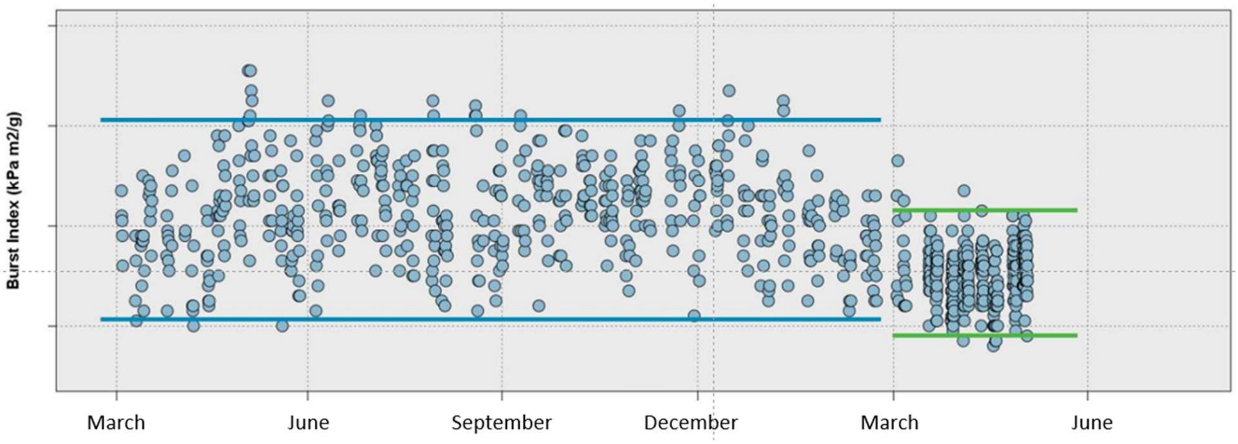


Figure 10. Burst variation before and after APC installation

Additional to the starch saving, the mill has also gained valuable insight to their process and their ability to affect their quality parameters. In the future it is also possible to build refiner controls so that depending on the price of energy and price of starch and other chemicals the APC can decide with what way it will build the strength properties the least expensive way. It would be optimizing the cost of the end product secondarily while optimizing the strength of the end product primarily.

POWER OF SELF-SERVICE ANALYTICS

- Build Your Own Dashboards – (New BYOD)

Edge cloud computing is reshaping the industry's approach to data management by bringing computational resources closer to the source of data generation. This paradigm shift reduces the need for data to travel to centralized data centers, thereby decreasing latency and enhancing the speed and reliability of data processing. In the context of the pulp and paper industry, edge computing enables faster adjustments to production processes in response to real-time data, leading to more efficient and agile operations.

Self-service analytics tools are revolutionizing the way data is utilized in the manufacturing sector. By enabling end-users to directly access and analyze data without the need for IT intervention, these tools promote a more data-driven culture within organizations. In the pulp and paper industry, self-service analytics can lead to greater data accuracy, optimized resource allocation, and cost efficiency, ultimately driving better business outcomes.

Key to empowering efficient data analytics is bringing the tools to all users, and specifically tools that do not require any special training courses to be utilized. This allows for generation of task specific or ad hoc dashboards whenever needed and leads to wide use of analytical tools by personnel that knows their own tasks and processes but need not be data analytics professionals. Figure 11 show a typical self-service dashboard from a board machine.

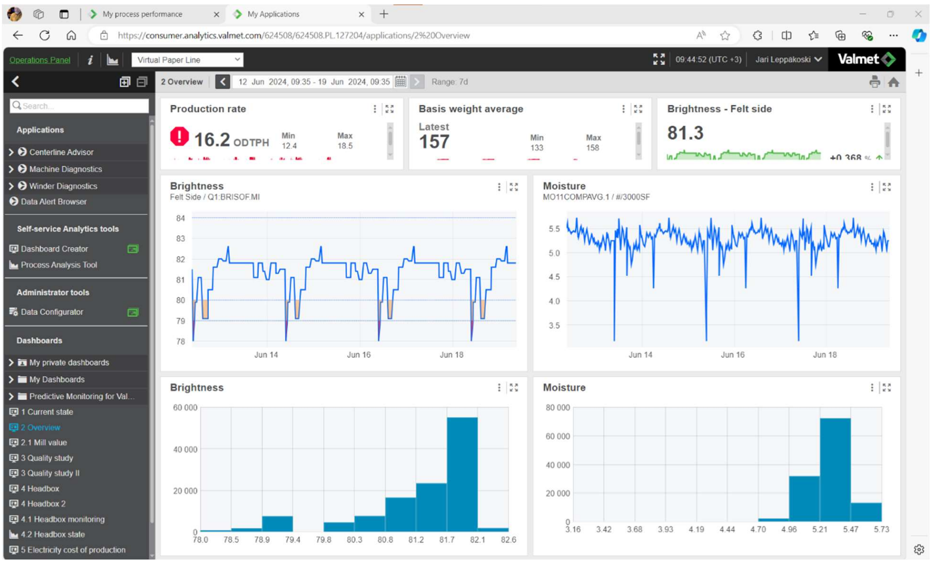
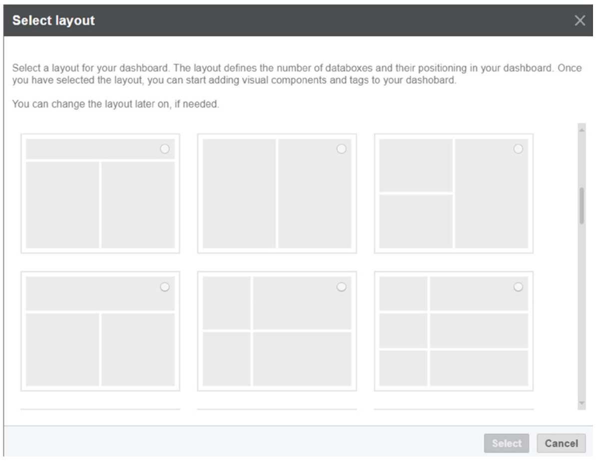


Figure 11, A Self-service dashboard

Creating task specific dashboards has been made very easy. User starts by selecting a visualization layout from a pre-defined set of layouts, show in the figure 12.


Select layout

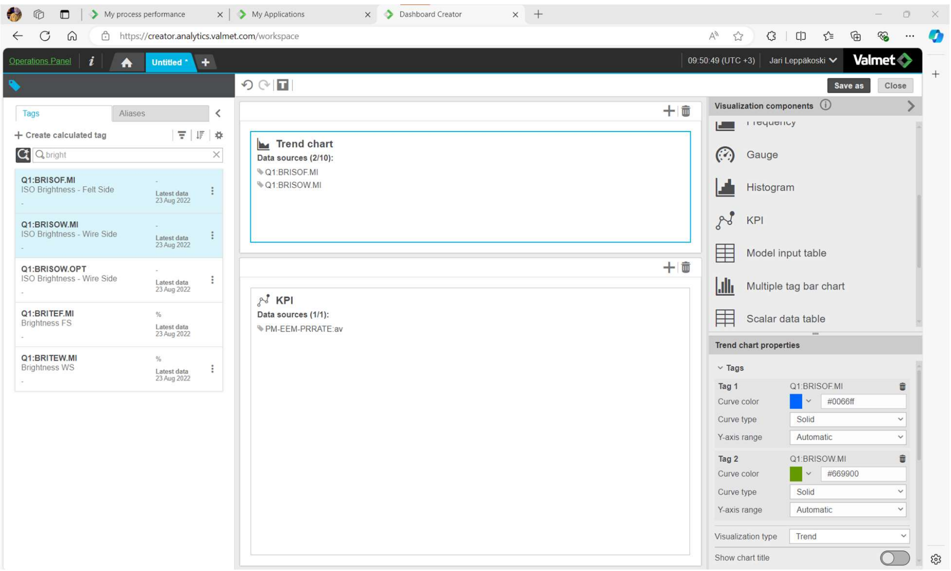
Select a layout for your dashboard. The layout defines the number of databoxes and their positioning in your dashboard. Once you have selected the layout, you can start adding visual components and tags to your dashobard.

You can change the layout later on, if needed.

Figure 12, selecting a dashboard layout.

After layout selection user selects what to show on each area of the layout from a list of visualizations, including all common visualization types such as KPI displays gauges, trends, histograms, data-tables and X-Y scatter. After that the user connects tags to the visualization component by selecting the tags from the list on left side of the display. The user does not need to know exact tag names, as the tag name can be searched based on name, description and unit as shown figure 13.

Data can then be further analyzed using the in-built data analytics tool that allow calculation of user defined tags and includes large set analytical tool such as data filtering, calculation of covariances and shifting the time of data, all with the emphasis of empowering the user instead of providing tools just for data-analytics specialist.



bright

Q1:BRISOF.MI ISO Brightness - Felt Side -	- Latest data 23 Aug 2022	⋮
Q1:BRISOW.MI ISO Brightness - Wire Side -	- Latest data 23 Aug 2022	⋮
Q1:BRISOW.OPT ISO Brightness - Wire Side -	- Latest data 23 Aug 2022	⋮
Q1:BRITEF.MI Brightness FS -	% Latest data 23 Aug 2022	⋮
Q1:BRITEW.MI Brightness WS -	% Latest data 23 Aug 2022	⋮

Trend chart
Data sources (2/10):
Q1:BRISOF.MI
Q1:BRISOW.MI

KPI
Data sources (1/1):
PM-EEM-PRRATE:av

Trend chart properties

Tags

Tag 1	Q1:BRISOF.MI	
Curve color	🟦	#0066ff
Curve type	Solid	
Y-axis range	Automatic	
Tag 2	Q1:BRISOW.MI	
Curve color	🟩	#669900
Curve type	Solid	
Y-axis range	Automatic	
Visualization type	Trend	
Show chart title	○	

Figure 13, Connecting data sources to the visualization components.

CONCLUSIONS

The renewed MPC control platform makes it possible to integrate new controls and measurements with the traditional linerboard-machine controls. It also allows for the easy creation of more unorthodox MV and CV control combinations, such as strength controlled by rod-hose pressure. The control itself can handle web management-level tasks while also being connectable with higher-level applications such as cost, energy, quality, or environmental optimizations.

The UX is designed to be intuitive and easy-to-use, even for individuals who are not specialists in the field of advanced process controls. The application includes automatic features to calculate the control and prediction horizons for each CV, as well as the possibility to automatically calculate weight factors for the MVs.

The modern MPC-based APC controls has been proven to enhance performance in multiple projects, especially during grade changes. The results show that the presented APC control package can be applied into various types of machines and into very diverse set of grammages.

Adoption of the Next-generation advanced process controls, followed by edge cloud computing, and self-service analytics into the pulp and paper industry represents a significant leap forward in the sector's digital transformation journey. These technologies not only enhance operational efficiency but also contribute to the industry's sustainability goals by reducing wastage of fibers, chemicals and energy consumption. As the industry continues to evolve, companies that embrace these digital innovations will be well-positioned to thrive in the competitive global marketplace.

ABBREVIATIONS

The following abbreviations are used in the manuscript:

APC	Advanced Process Control
ADV	Advanced control high-level actuator variable
ADVMV	Advanced control low-level actuator variable
CV	Controlled Variable
DV	Disturbance Variable
ETFE	Empirical Transfer Function Estimate
EXT	External variable
GSM	Grams per Square Meter
J/W-ratio	Jet to Wire ratio
MD	Machine Direction
MLBS	Maximum Length Binary Sequence
MPC	Model Predictive Control
MV	Manipulated Variable
OCC	Old Corrugated Container
PRBS	Pseudorandom binary sequence
SPA	Single page web application
SS	Soft Sensor

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