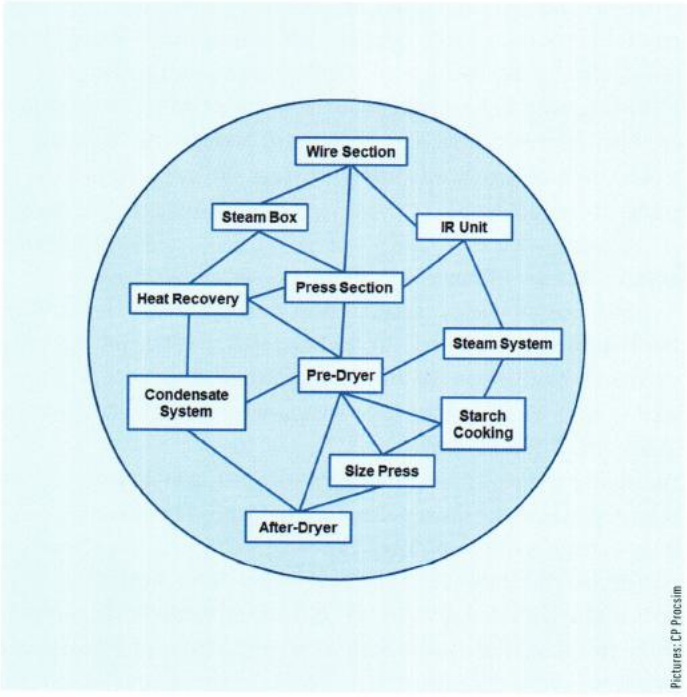
Digital Twin

This description is a continuation of the paper "Up to 8 % Reduction in steam consumption in the drying process of paper machines through "Simulation Aided Control" issued in the spring edition Paper Technology International 2025.

Author: Dr Peter Fisera, CP Procsim, office@procsim.eu

Heart of the new process control technology



Pictures: CP Procsim

Fig. 1: Simplified example of the interconnection of the control loops. All control loops are immediately and continuously "informed" about the current status of the system and the control reactions are synchronized.

Digital Twins are on everyone's lips - also in the paper industry. However, the functionality, application, and benefits of this technology are not clearly defined. This article is an attempt to describe the characteristics and use of this new process control technology in a simple way, using examples.

Let us start with the following sentences: A Digital Twin is a derivative of a mathematical model of real technological processes, which reflects all relevant process variables - both measured and unmeasured. This modeling is based on the laws of physics and thermodynamics. These models are capable of representing the technological process autonomously, even without being connected to measured process data. This is the key difference from data-driven models, which only function when linked to real-time process data.

The new process control technology can be defined as follows: "Simulation Aided Control" of technological processes is a tool for unlocking existing production capacity, harmonizing energy use, and increasing plant efficiency to achieve the best possible performance level. This technology far surpasses previous control approaches used in the paper industry. It is incomparably faster, more precise, and more complex than standard MPC (Model Predictive Control) techniques. The control loops are "informed" not only about the current state of the entire process but also about its dynamic development in the near future.

The Digital Twin is a virtual image of the real process. Every single process variable - whether measured or not - has a "small digital counterpart" in this virtual process. Not only physical quantities like temperature, flow, and pressure are precisely controlled, but also quality-related pointers on features such as surface

inconsistencies, delamination, or yellowing are simulated and causes are eliminated using sophisticated control strategies.
The Digital Twin stands out for its wide range of possible applications. These include operator training, process design validation, multivariable soft sensors, providing information on equipment wear for maintenance purposes, and even complete process control.

Digital Twin – simplified description

Essentially, it's about the application of well-known physical relationships during dewatering and drying. The entire papermaking process is broken down into elementary processes, which are then described mathematically and linked together again, creating virtual processes.
These are processes such as: dewatering in the press section, evaporation, heating of paper by conductive, convective and radiative heat transfer, air movement in the duct system and especially the properties of steam in the air and paper as enthalpy, entropy, pressure, temperature, evaporation heat and others.
No less important are the equipment geometrical and technical parameters. These parameters are the limiting conditions for the system of equations representing the entire dewatering and drying process. Nevertheless, this is not yet a Digital Twin!
Only after validation does the model become a Digital Twin. Validation involves calibrating the model parameters to achieve the same or very similar model results by comparing the measured values for all working points of the real machine.
The high efficiency and precision of the drying process control is based on the mathematical linking of all individual processes running in parallel. In this way, every single control loop is "informed" about the reactions of other control loops and calculates control steps accordingly. A serious obstacle of current control techniques is the process dwelling time (sometimes minutes). To avoid overreaction the control loops must be even slower. This makes the control task inflexible and decreases its precision. The Digital Twin eliminates this dwelling time practically to zero. Control steps lead directly to the target in the shortest possible time (technical and technological). (Fig. 1)

Digital Twin – Applications

→ **Process control:** Digital Twin simulates results of new target values long before they can be measured. The simulated result is the window into the future. A connected optimizer (automationX product) is a software that continuously searches (using digital twin) for the best setpoints in order to minimize energy consumption. Within a few seconds, hundreds of operating points are simulated while maintaining (simulated) production and quality. The best one (according to the optimization criteria) is used for new process setpoints. This technology has been proven to reduce energy consumption for the drying process by between 5 und 10%.
Not only energy savings, but also quality is controlled using simulated process variables as soft sensors. For example: the simulated cylinder surface temperature is used as a control variable to avoid the formation of steam bubbles between paper and cylinder surface or partial lift off.

→ **Soft sensors:** Every single process variable (measured or not measured) has its own small digital twin in the model (process simulator). Over 1000 new high precision "soft sensors" (calculated values) even for difficult to measure process information can be used as a real measured value for process viewing or process control. A web dryness after the press section or cylinder surface temperature are examples of not measured but extremely important process information.

→ **Maintenance:** Immediately after the validation period, the actual equipment parameters as well as the equipment performance (e.g., felt dewatering parameters, heat exchanger efficiency and others) were the same (or very similar) to the model behavior. Those real parameters are getting worse over time while the model parameters stay unchanged. Comparison of actual performance with model performance quantifies the extent and economically evaluates higher energy costs.

→ **Upgrade review:** The impact of planned investments in upgrades and/or expansions can already be evaluated at a very early stage (feasibility phase), providing valuable information for the investment decision. This significantly reduces investment risk.

→ **Operator training:** The dynamic process simulator is a valuable tool that helps operators reduce errors in the control room, thus avoiding potential upsets or production downtimes. The operators learn the process and the complexity of the control task as if operating a real process, however risk free. These speeds up the education and makes it extremely intensive.

→ **Drying curve:** The drying curve online! Digital Twin calculates the drying process in MD direction step by step. For example: the web temperature at the cylinder exit points is in many cases an important paper quality factor, anyhow impossible to measure online. The optimizer can control MD web temperature and calculate the steam pressure setpoint for each particular cylinder group accordingly. (Fig. 2) It is an incomparable sophisticated approach to standard cylinder group cascade control.

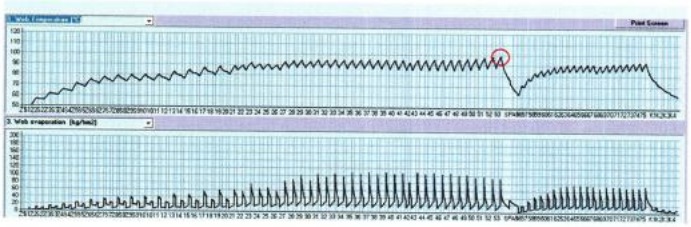


Fig. 2: An example of the soft sensor's diverse possibilities. Online detailed drying curve for paper web temperature and evaporation rate in a multi cylinder paper machine. The calculated paper temperature (close to 100°C – red circle) may be a pointer of impaired quality of the paper surface.

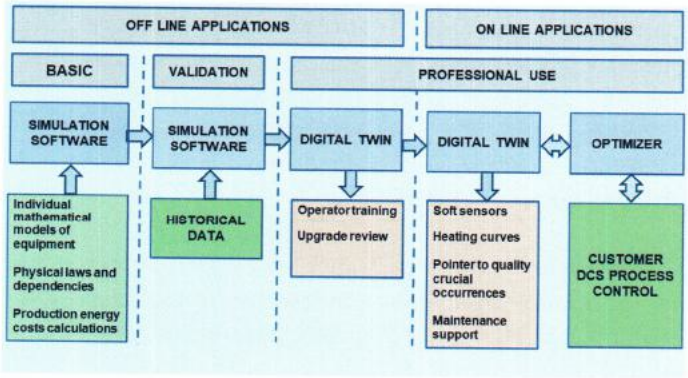


Fig 3: Structure of applications

→ **Structure of applications:** The Digital Twin can be used both online and offline. Naturally, the greatest advantage comes from online use, as this offers the highest savings potential - up to 10% lower energy for drying process, which represents about 6% lower energy costs for the plant! However, it can also be used offline, for example to train employees or to better analyze historical data. (Fig. 3)

Digital Twin – Development

The development of the Digital Twin software for the control of technological processes is a continual process. Not only Digital Twin but also the optimizing software is continuously adapted to the new criteria such as frequent changes in energy prices. The following areas are permanently analyzed and the results are included into the digital twin software solutions:

- → Energy reduction in individual processes of paper drying
- → Effect of wear on energy costs (Dewatering efficiency, Heat recuperation)
- → Energy costs evaluation in real time absolute and relative to production
- → Evaluation of CO_2 emissions in real time
- → Impact of changes in raw material on dewatering and consequently energy consumption for drying.
- → Exploring the limits of safe drying to increase production while maintaining consistent quality

The dynamic structure of energy prices, especially electricity, is taken into account in real time when calculating costs and enables a dual-mode operation, provided the paper machine meets the necessary conditions. The cost differences are continuously recorded and provide valuable insights for future investments. This allows the economic viability of operating electric boilers or heat pumps in the future to be assessed.

Developed process simulations

- → Paper machine for all paper and board grades
- → Coating machine for all types of drying equipment and coating layers
- → Pulp drying machine
- → Batch digester house
- → Steam network for papermills
- → Yankee machine - MG and Tissue grades

The optimization software controls the real and virtual process with exactly the same setpoints. The control strategy is based on the search for the best setpoints in the Digital Twin and subsequently their application in the real process. This control technology not only reduces energy consumption, but more importantly, ensures that the devices perform at their best.

Digital Twin – Solution potentials

- → Energy reduction up to 10 %
- → Production increase by 2 %
- → Soft sensors for difficult to measure process variables
- → Development of solutions for quality disturbing occurrences
- → Secure review and fine-tune machine upgrades
- → Payback less than 1 year

Digital Twin – References

Recent implementations demonstrate substantial savings:

- → Smurfit Kappa PM9, UK: Over 7 % energy reduction focused on hoods and condensate control and paper drying process.
- → Weig Karton KM6, Germany: Over 5 % energy savings in coating and pre-dryer sections.

Awarding

- → first prize for sustainability by CPI in England 2022,
- → first prize for the best project by VNP in Netherlands 2023
- → second prize Constantinus by WKÖ in Austria 2023.

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roman.klug@automationX.com office@procsim.eu sales@wolfheilmann.eu