ARTIFICIAL INTELLIGENCE

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Optimize Sugar Production with AI

AI-enabled optimization improves operations and maximizes sugar mill profitability

By Brett Stewart, PhD - AI Solutions Director, C3 A

Digital Transformation Requires a Different Approach

Sugar manufacturers are embracing digital transformation. Many have started this journey by increasing the amount of data collected at sugar mills and in the sugar production process. However, data do not generate value on their own and sugar manufacturers seek to apply AI on top of the data to improve operational decisions.

This AI-based approach improves the mill's ability to dynamically optimize operations against changing conditions and improves individual operator performance. By bringing together disparate data sources and applying advanced optimization algorithms on top, the AI-based approach enables near real time process optimization. With AI-enhanced decision making, each operator performs like an expert operator and helps maximize mill profitability with higher cane throughput, improved yields, and lower energy costs.

Data do not generate value on their own. Applying AI on top of data drives improved decision making.

The Challenge: Dynamic Conditions, Siloed Data, and Varying Operator Expertise

Sugar extraction mills face unpredictable and dynamic operating environments. Warmer, unpredictable weather reduces harvest yields. Faced with lower harvest yield, manufacturers and plant operators are hard-pressed to recover as much sugar as possible from each ton of harvest. This challenge spurs investment in additional equipment and a focus on process improvements to extract more sugar from the cane.

To drive additional improvements, sugar manufacturers have started the decades-long process to generate and capture more data streams such as more frequent cane feed data, juice and syrup quality data from continuous analyzers, and milling and clarification process data from new instrumentation. However, vast quantities of the data remain underutilized due to data siloes. As the quantity of the data has increased, each database has been fragmented into its own system. Lab data are stored in a lab data system. Programmable logic controller (PLC) data are captured and stored in a process historian. Weather data, maintenance data, process upsets, manufacturing data, and pricing data all exist in separate systems. Although these data are available, it is a challenge to unify them and generate actionable insights for the process personnel who is responsible for the day-to-day operational decisions.

Operational and Technological Challenges Faced by Sugar Manufacturers

Operating conditions change constantly (e.g., temperature, pressure)	Siloed data systems (e.g., PLC data, lab data, P&IDs)	Varying operator experience

Moreover, sugar yield and optimal process settings are dependent on operator experience and risk tolerance. After finding a stable operating point, less-experienced operators can be reluctant to implement process changes because they are less comfortable with the mill-wide implications of changing setpoints. As their process knowledge improves with experience, operators gain the confidence and skill set to dynamically optimize operations. As a result, the most experienced operators can significantly outperform their peers in sugar yield.

Dynamic conditions, siloed data, and a dependence on operator experience impact yield in manufacturing processes.

Real-Life Example: Incorporating Cane Quality Data

Consider this: a plant wants to improve operating decisions with timely cane quality data, and as a first step, the plant must collect periodic quality samples. However, this sampling process is error prone and can mislead operators, resulting in reduced throughput or poor product quality.

To add to the challenge, cane quality data are useful to daily operations only if they are combined with PLC operational data such as juice flow rates, pH, and temperature. These data from disparate systems must be unified into a single data set and interpreted by engineers to provide operating guidance. This guidance must then be further interpreted by operators who use their understanding of the process dynamics and constraints to make setpoint adjustments.

Even with a simple example of incorporating cane quality data to improve operating decisions, the process of generating value from data is complex and time-consuming. The data do not provide value on their own. Process knowledge and experience must be applied on top to convert the data into actionable analysis, a process that is dependent on the experience and availability of the operations staff.

What if you could have your most experienced staff always available to provide the highest quality recommendations?

Path to Continuously Optimized Operations: The AI-Driven Approach

The AI-driven optimization approach combines advanced data unification and optimization capabilities with codified subject matter expertise to enable continuous process optimization and improvement.

At the foundation of the AI-driven approach is the unified data model, or the digital twin. The data model unifies data from various systems such as lab data, process historians, and process and instrumentation diagrams to create a unique representation of each sugar mill. The model encodes the production processes, the physical assets, and their interdependencies, accounting for how each parameter or control setpoint affects the end-to-end sugar milling process, from extraction, clarification, and evaporation to crystallization.

AI-based optimization tailored to improve the sugar milling process is applied on top of the unified data model to enable near real time and continuous process optimization. Leveraging operator experience and each mill's unique data set, AI learns the expected behaviors of the equipment and processes. Once the operating baseline has been established, the optimization model can begin recommending setpoints that improve yield while simultaneously observing constraints such as maximum pump amperage, steam availability, bagasse humidity, syrup brix, juice turbidity, and other equipment and quality constraints. These setpoints are configured to maximize profit, using current sugar and energy prices to ensure the most economic trade-offs are made.

How AI Is Incorporated into the Operator Workflow

1. **Unify data from various sources**
2. **Create a digital twin for each sugar mill using its own unique dataset**
3. **Apply AI-driven optimization to generate optimized process setpoints**
4. **Operator reviews AI-driven recommendations**
5. **Operator updates setpoints and consistently optimizes the process**

AI-based setpoint recommendations and operational insights are served through an intuitive application user interface and workflow, allowing operators to act quickly. To validate setpoint recommendations, operators can review process constraints, historical setpoint values, and trend analysis of key process variables. Once validated, the operator can accept the recommendation and implement the setpoint changes. Additionally, the AI model generates KPIs to measure value captured or lost based on accepted or rejected AI recommendations to inform future operator decisions.

The AI-enhanced approach is important to distinguish from automation. While automation is valuable, excessive automation can slow the essential experience-driven knowledge building that occurs as operators implement setpoints themselves. The AI-based optimization becomes a part of the team to improve operations without denying the operators critical learning opportunities. This allows the operators to understand the process and become partners in driving improvements to the AI.

AI solutions enable continuous process optimization in near real time, drawing on insights from data and operational expertise.

The AI-Driven Optimization Framework

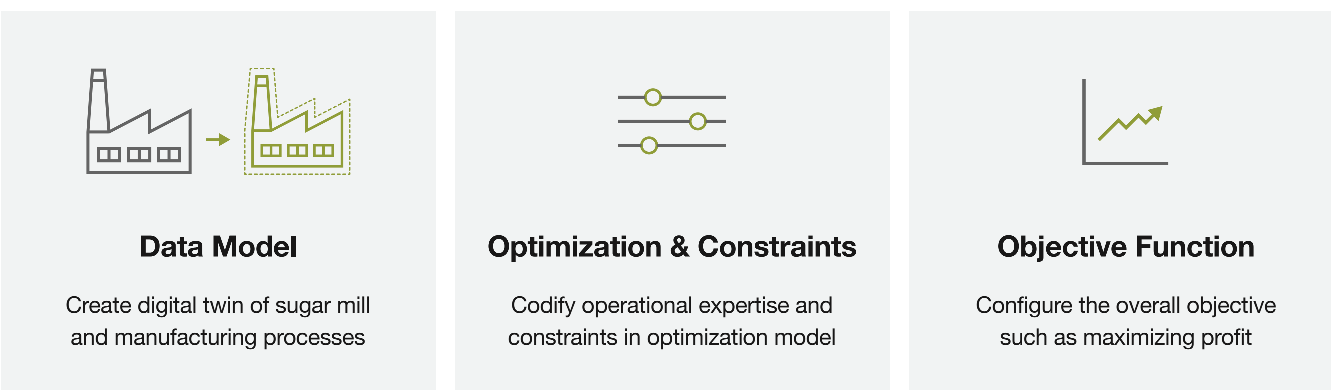
The AI-driven optimization framework consists of three primary parts: the data model, the constraints, and the objective function. These parts are all derived from operations data and operator knowledge, and each is tailored specifically to the unique attributes of the sugar milling process.

1. **Data Model**

   The data model is a digital twin of the process and incorporates all the important processes in the mill that affect sugar extraction and recovery. To construct the digital twin, the following data streams are used:

   - **Programmable Logic Controller (PLC) Data:** PLC data are usually the richest data set and form the core of the manufacturing data used in AI-driven optimization. These data are used to build AI models that track how sugar moves throughout the entire process and predict key constraints.
   - **Lab Data:** Lab data are expensive to collect and prone to error but are critical for determining product quality and predicting yield from cane. Data must first be cleaned to remove outliers and other inconsistent data. Then the data are combined with PLC data to develop AI-based virtual sensors to predict the lab properties in near-real time.
   - **Process Flow Diagrams / Piping and Instrumentation Diagrams (PFDs/P&IDs):** Although general principles apply to every mill, each mill is configured in a unique way. For instance, the number of milling stations, clarifiers, and evaporators is chosen based on the regional climate. The diagrams illustrate the process flows between equipment, which can become complex as the mill has been debottlenecked and expanded over time. Using these diagrams, the AI model can be configured as a digital twin to provide the correct sensor configuration and ensure the model represents the correct physics of the process. AI-based diagram parsing can accelerate digital twin development with automatic extraction and mapping of sensor and equipment IDs from P&IDs.

AI-Enabled Optimization Approach Consists of Three Primary Parts



2. **Optimization Model & Constraints**

   Experienced operations staff and knowledgeable operators are critical in identifying the important constraints to incorporate into the AI-based optimization model. Identified constraints can then be verified and validated with the following data:

   - **Equipment Data Sheets:** Once the optimization model is in place, operators are pushed to expand the capabilities of the process. It is imperative that the actual process limits be incorporated into the optimization model and not the “usual” limits that operators are used to. For example, the actual pump flow limits (e.g., speed, amperage, NPSH) should be used to estimate the true maximum flow output. Using these limits helps the optimization push towards true constraints and avoids artificially limiting the process.

- **Specifications:** Intermediate products such as clarified juice and evaporator syrup provide leading indicators for quality of the final sugar. The specifications for these intermediates guide chemical addition and energy usage. However, operators often back off from the true specifications to leave buffer for lab error and other uncertainty. Using the virtual AI sensors, the digital twin can predict the lab samples based on process changes, build more confidence in the AI-driven recommendations, and allow operators to push closer to the true operational limit.

3. **Objective Function**

   In many cases the objective of the optimization model is to maximize the profit of the overall sugar mill. This requires accounting for the relative profitability of the final products and cost of energy. The latest economic data should be used, including current market value for sugar and byproducts such as molasses and bagasse (i.e., energy).

Real-Life Example: Adjusting Imbibition Water to Maximize Sugar Yield

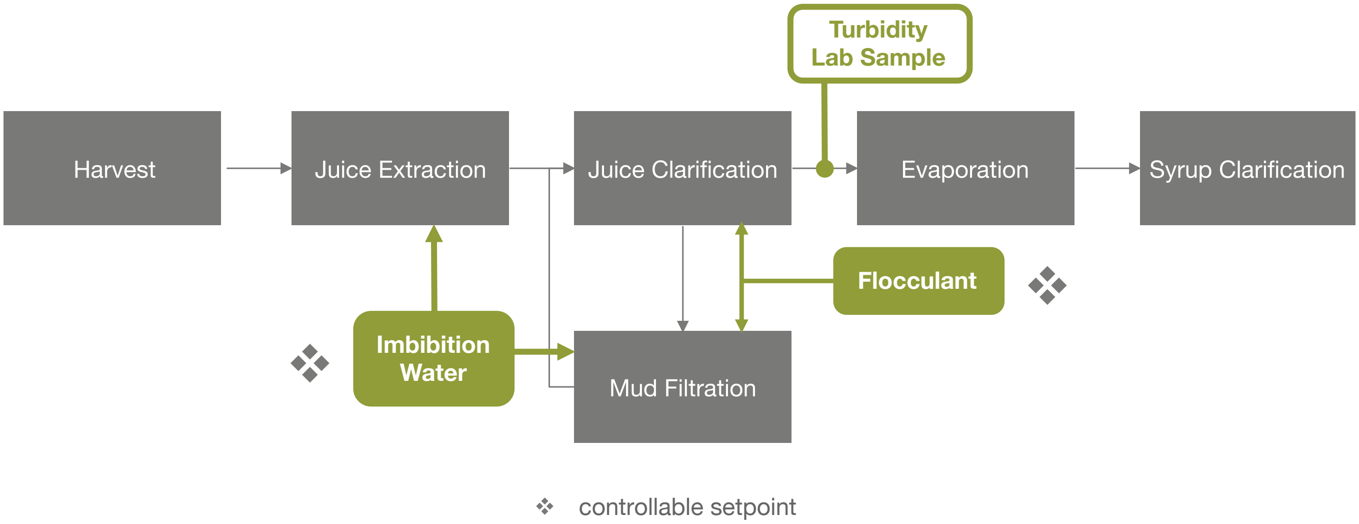
As an example, imbibition water is used to extract more sugar out of the cane in the mill. It is well understood that additional water improves sugar yield, but water cannot be added indefinitely. Every additional gallon of water requires more clarification and evaporator capacity, which are limited by throughput and steam constraints. If too much water is added, the clarifier residence time could be reduced to the extent that impurities cannot be sufficiently removed from the clear juice, leading to further downstream effects such as higher turbidity and poor crystallization. Consequently, mill operators can be reluctant to increase water even if there is available clarifier capacity.

Using ML models trained on data from the mill stations and clarifier, the AI-enabled optimization model predicts how additional water affects clarifier residence time and its impact on clear juice quality. The model then recommends the maximum water addition possible before turbidity becomes too high. The mill station operator can review this recommendation and update the setpoints accordingly, knowing that the additional water does not exceed the clarifier capacity but would help maximize sugar extraction from the cane.

AI-driven optimization finds the right trade-offs between process variables, allowing operators to choose the best setpoints.

The optimization can be further improved by including clarifier setpoints in the model. For instance, even more water can be added if additional flocculant is available to offset the decreased residence time. By incorporating all available setpoints, AI-driven optimization can find the right trade-off between extraction and chemicals, understanding relative costs and benefits of each and helping operators find the optimal path to higher profitability.

AI-Enabled Optimization Accounts for Process Trade-Offs to Identify Optimal Setpoints



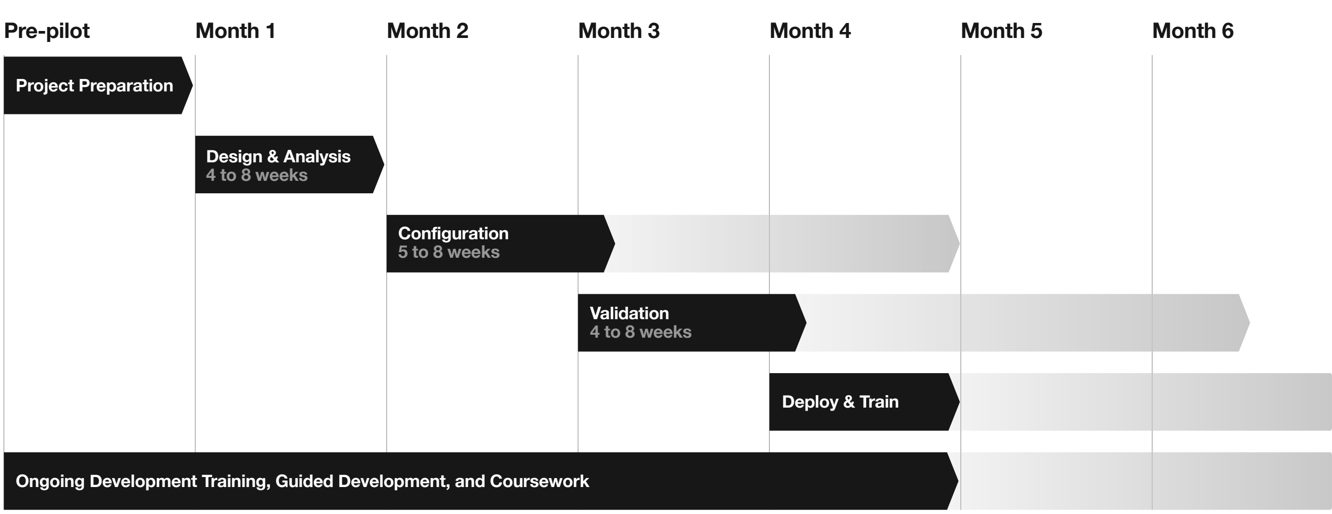
Act Today: Get Started with C3 AI

Lower margins, tighter environmental constraints, and experience attrition are intensifying the process optimization challenge for sugar manufacturers.

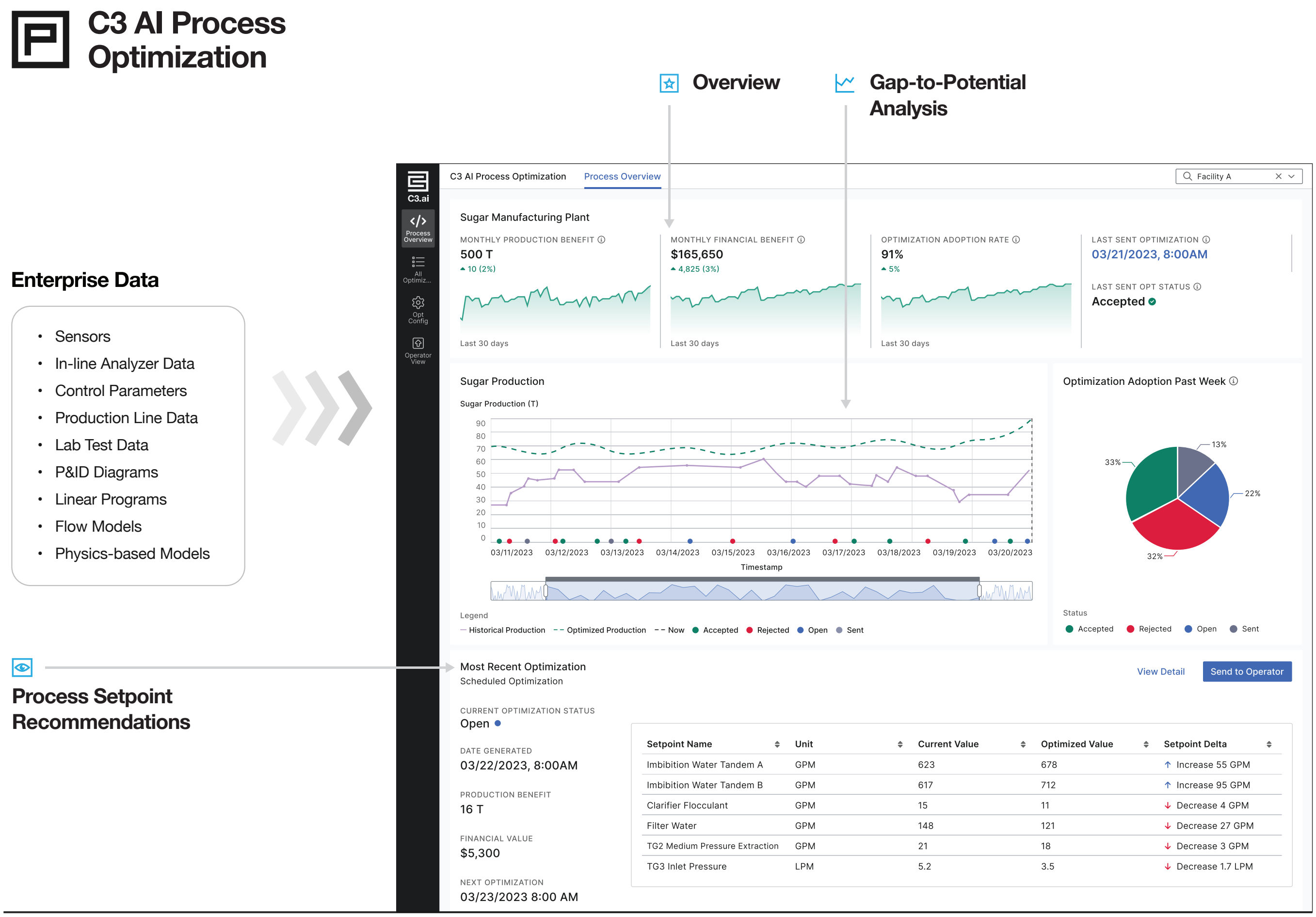
Even though sugar manufacturers are increasing the quantity and quality of their data streams to find operational improvements, increased data gathering is not enough. AI-based solutions combine the high volume of data with advanced ML capabilities and codified operational expertise to provide actionable insights that enable each operator to perform like an expert operator and maximize plant profitability.

C3 AI has been a proven digital transformation partner for sugar manufacturers. As part of the C3 AI Reliability Suite, sugar and other manufacturers have adopted C3 AI Process Optimization to increase yield and profitability. Combining customer's business and process knowledge with C3 AI's experience in AI, C3 AI Process Optimization can be deployed and achieve immediate results within six months. Get in touch today to start your AI journey.

C3 AI Pilot Timeline: Deliver a production AI application in 4-6 months



Solution Architecture



About the Author

Brett Stewart, PhD is an AI Solutions Director at C3 AI. Drawing from 15 years of manufacturing experience, he partners with customers to develop and implement tailored AI solutions to solve business challenges. Prior to C3 AI, Brett was an optimization engineer at ExxonMobil. He holds a Bachelor of Science in Chemical Engineering from The University of Texas at Austin and a Doctor of Philosophy in Chemical Engineering from the University of Wisconsin-Madison.

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