

Process Line Debottlenecking and Process Improvement Through an Empirical Data-Driven Model

Authors

B. Beleski, Process Engineer, Hatch, Pittsburgh, Pa., USA
britta.beleski@hatch.com

H. McGinley, Process Engineer, Hatch, Pittsburgh, Pa., USA
hannah.mcginley@hatch.com

K. VanNess, Process Engineer, Hatch, Chicago, Ill., USA
karleigh.vanness@hatch.com

This article will discuss the development and troubleshooting capability of a process debottlenecking model for steel production facilities. This model utilizes Excel-based modules, incorporating production data, equipment designs and capabilities, and maintenance/delay information to build a customized replica of a process unit. Once the model is validated, different scenarios are tested to identify opportunities for equipment modifications or operational changes that can debottleneck the process unit, increase production capacity and help reduce carbon emissions. This article will detail use cases, as well as opportunities for applying the model results.

Introduction

Hatch is engaged by steel producers globally to evaluate the operation of process lines through a debottlenecking model, which provides options to increase capacity or reduce cost. While many options may be available to debottleneck specific process areas or operational challenges, cost, schedule and level of difficulty are evaluated against each opportunity to provide an overall recommendation for improvement to a process line. The debottlenecking model is typically applied to continuous paint lines and galvanizing lines but can be manipulated to suit most steel processing lines and has been used on more than 20 process lines in varying levels of detail by Hatch over the years.

The Hatch strip process line production model is a tool for quantitatively determining line throughput by calculating theoretical maximum speed through each process stage and testing the line capacity under future production scenarios. It has a graphical output that provides visual insight into the line bottlenecks by product that then becomes the basis against which future production scenarios are compared.

Modeling Development

The first step in model development is establishing a data-driven baseline

model. Producing an accurate representation of current operations through product mix, operating hours and line functionality is fundamental in establishing impactful upgrade recommendations. Therefore, the data collection process to establish the base case is the most important part of the debottlenecking process and is the foundation upon which all future scenarios and upgrade recommendations are built. Data collection can be broadly categorized into two main areas:

1. Technical Design Parameters.
 - Line layout and drawings: processing equipment configurations, dimensional data and general arrangement details.
 - Original equipment design specifications: spray header quantities, nozzle types, design fan power and speeds, heating capabilities, burner design, drive speeds, etc.
 - Equipment modifications: records of past upgrades and design changes.
 - Permitting and safety limitations: permissible percent of lower explosive limits (LELs) in paint ovens or levels of volatile organic compounds

- (VOCs) in the regenerative thermal oxidizer (RTO).
 - Utilities information: natural gas and electricity availability and spare capacity.
2. Operating Performance Parameters.
- Historical coil production data: production log example (Fig. 1).
 - Historical delay logs: records of all planned and unplanned outages.
 - Operating trends through time studies or iBA/PI data: oven/furnace atmosphere temperatures, strip temperatures/peak metal temperature (PMT), coil changeover steps and durations, and temperature and flow measurements in auxiliary equipment or utilities.
 - Maintenance information: scheduled maintenance for a year, common unscheduled or corrective maintenance, and duration of key maintenance activities.
- Interviews with site team: discussions with operating, maintenance, and engineering staff to gain insight into known bottlenecks, previous improvement work and future production goals or planned projects.
 - Site visits: validate line operation against design.
 - Continuous paint line data: paint types, dry film thickness (DFT), dwell times, percent solids by paint type, rheology of various paint and curing requirements of paints.
 - Galvanizing line data: coating mass targets, passivation and resin types, furnace cycles, and strip cooling data.

Fig. 1 shows an example of coil production log data requested.

Model Setup

Once the necessary data and input information have been gathered, the base case scenario model can be developed, starting with line-specific process modules. The base case model is a recreation of the line setup and operational

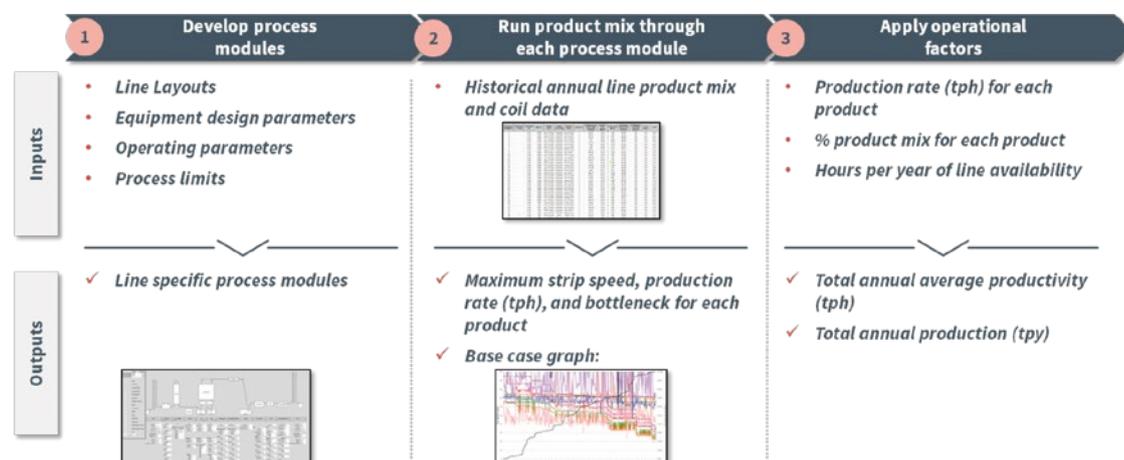
Figure 1

Reference coil data.

GRADE	COATING WEIGHT	COIL MASS IN	COIL MASS OUT	LINESPEED	WIDTH	GAUGE	TEMP_Z10	TEMP_Z1 1	TEMP_Z1 2	TEMP_Z1 3	DIFF Temp Out	RTF Temp Out
S320GD	255	22.4	23.49	129	1240	0.72	483	443	439	331	639	722
S320GD	255	17.2	18.23	174	1240	0.535	495	412	415	459	654	737
S320GD	255	21.72	23.3	164	1240	0.535	479	445	444	404	630	718
S320GD	255	21.68	22.77	173	1240	0.535	421	296	407	356	639	716
S320GD	255	21.92	23.16	129	1240	0.74	475	436	432	326	651	721
S320GD	255	19.2	20.44	159	1079	0.5	488	444	435	322	638	721
S320GD	255	19.36	20.4	166	1240	0.6	478	437	433	324	653	719
S320GD	255	22.74	23.95	136	1240	0.72	475	434	432	333	641	721

Figure 2

Debottlenecking model inputs and outputs.



parameters for a typical year, serving as a snapshot of steady-state operations. Fig. 2 illustrates how inputs drive the debottlenecking process, with outputs indicating bottlenecks and potential areas for improvement.

Each process module is intended to replicate the conditions of different equipment or sections of the line. Modules are fully customizable to suit the unique design of the line and can include, but are not limited to:

- Entry and exit coil size and changeover cycle time.
- Entry and exit accumulator capacity and time required to recover accumulator position.
- Cleaning section (qualitative assessment).
- Paint line process modules:
 - Roll on pretreatment drying.
 - Prime and finish oven heating capacity.
 - %LEL levels.
 - Solvent loading and RTO or incinerator capability.
 - Prime and finish quenches.
- Galvanizing line process modules:
 - Furnace sections: preheat zone if applicable, direct-fired furnace (DFF) or nonoxidizing furnace (NOF), and radiant tube furnace (RTF).
 - Gas jet cooling and overaging zone.
 - Coating mass control systems.
 - After-pot cooling (APC).
 - Quench.
 - Dryer(s).
 - Chemical treatment.

Case Study – Model Results

Model Results

Once the model is set up and executed using the provided operating data as the input, the first validation step is to reconcile the theoretical model outputs with the known production of the line. On most lines, the average speed achieved for each product is slightly below the theoretical maximum equipment capacity due to slowdowns, start-up conditions, quality issues or line stoppages. In order to adjust the model to reflect real-world production, a run rate factor is applied to the predicted tonnage so that it aligns with the known line throughput. If the run rate factor is close to 100%, the model is effectively capturing production stoppages. A lower run rate factor may indicate that certain products are produced at noticeably lower speeds than the theoretical maximum calculated by the model, or that quality issues/operational protocols are imposing additional restrictions.

Following any necessary calibration to match known throughput and align with feedback from the site team,

the model is established as the base case scenario upon which any upgrades can be assessed. A primary output of the model is a graph that serves as a visual representation of the product-by-product speed limits for various process areas. This graph can be used to identify the bottleneck area for each unique product, as well as areas that affect the largest proportion of the product mix. For illustrative purposes, representative production data sets were constructed for both a galvanizing line and a paint line by compiling and modifying data from several operations. This allows for a model example that is operationally plausible without disclosing real plant performance.

Fig. 3 shows an example of the output graph for a continuous paint line, using the mock production data as an input. This chart should be read as follows:

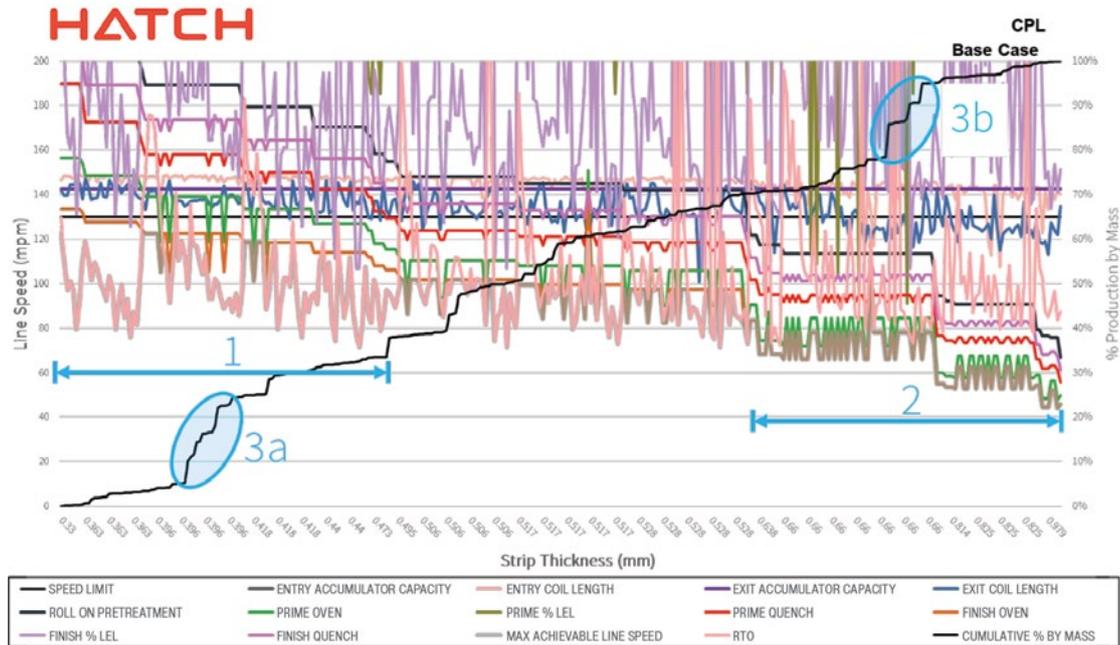
- x-axis: Increasing gauge left to right.
- y-axis (left side): Line speed – used for bottleneck processes and for current average process speed.
- y-axis (right side): Percent of product mix at each unique product on the x-axis.
- Individual Chart Elements: Each line indicates the maximum achievable speed by unique product for the model unit, calculated using the design and operating parameters.
- Max Achievable Speed: This indicates the model-calculated maximum achievable speed for each unique product based on the speed limitations of each process section. The minimum speed for any given product across all model units is the maximum achievable speed for the product, and this speed is used to calculate a production rate.
- Cumulative % by Mass: This is the cumulative percentage by mass of the product mix that is present at that x-value of the graph. This is the only graph referenced to the right-hand side y-axis.

Some key observations from Fig. 3 (indicated by blue numbers) include:

1. At light gauges, the line speed and, ultimately, production is limited by the RTO and represents about 40% of the product mix by mass. For many light-gauge products, a single bottleneck may dictate speed, offering a straightforward opportunity for production increase over a portion of the product mix.
2. At heavier gauges, approximately 30% of the product mix is production limited by multiple bottlenecks close together. In order to achieve a significant increase in line speed, upgrades would need to be made to both the prime and finish ovens concurrently. Line speed increases of heavier-gauge products result in a larger increase in overall throughput, making this an important area to target.

Figure 3

Continuous paint line graphical output.



3. Step increases in the cumulative percent by mass indicate gauges that dominate the product mix, meriting special attention for improvements.

Case Study – Upgrade Scenarios and Future Road Mapping

As key bottlenecks are identified using the model outputs, Hatch brainstorms upgrades and solutions to address these bottlenecks. In this brainstorming session, Hatch's global experience with numerous process lines and internal subject matter experts provide insight and creativity in design to ensure that bottlenecks can be addressed with industry-standard approaches, unique client-specific solutions, or technologically advanced solutions within the commercial and operational constraints of the project. Upgrade opportunity reviews held with the client team and the Hatch team facilitate discussion around the practicality of the modification for the specific client and line, as well as encourage collaboration among the client and Hatch team, leading to novel solutions.

Generally, there are three possible avenues for achieving higher productivity. First, process bottlenecks can be identified by the model and removed by upgrading equipment accordingly, which allows the line to run at a higher maximum speed. Second, operating time can be increased by reducing and/or eliminating outage time. Lastly, prime production rate, or the percentage of products that do not need to be rerun through the line or reduced to nonprime quality, can be increased by addressing quality issues. Depending on client production

increase targets, a running list of upgrades is created to restore the line to original design capacity (if line is currently operating below design) and/or upgrade the line to exceed original capacity.

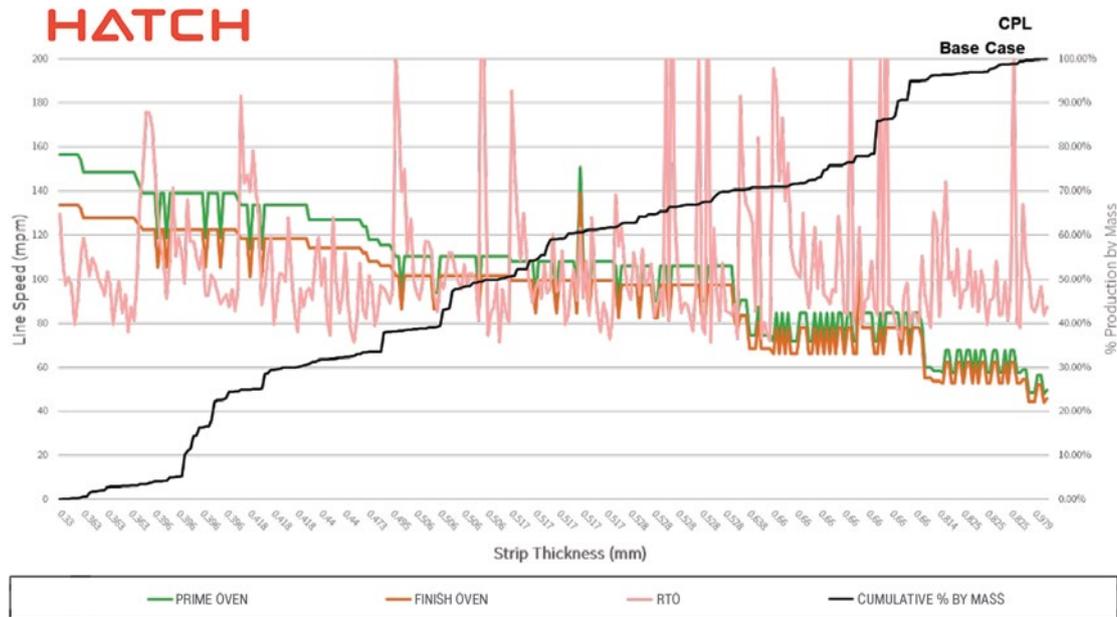
In this option development exercise, upgrades to accommodate changes in operational requirements or product mix over time are considered (reduced finish coil sizes, a shift to lighter-gauge products that approach the limits of the terminal equipment, etc.). Additionally, consideration is given to any upgrades to process bottleneck areas that would bring the line on par with industry norms (e.g., upgrading jet cooling from the older design of slow jet cooling to gas jet cooling units to debottleneck the cooling after the galvanizing furnace, or installing a regenerative thermal oxidizer for a paint line to allow line speed increases even at high-VOC paint types). Finally, new and emerging technologies are introduced to provide outside-the-box opportunities that may apply to process units of the line. This option development phase may generate a large list of ideas with varying degrees of practicality, implementation difficulty and cost impact.

After the base case model is analyzed, a list of process areas to be targeted for upgrades and potential upgrade options is developed. This list is then narrowed down based on client preference, commercial or technical constraints, acceptable risk, and proven solution maturity.

Phasing of the upgrades is also important to consider, as a facility may be able to justify a smaller capital investment for a portion of the possible production increase at first, and a greater return on investment as the production

Figure 4

Continuous paint line simplified graphical output.



increases are realized. Oftentimes, there are operational improvements that can result in production increases with no or minimal capital investment, so it is usually recommended that these are trialed first. Generally, options with the potential for a higher tonnage increase to investment ratio are prioritized over those options that are higher cost or risk for a lower payback.

Case Study – Paint Line

For the example paint line data set, the base case output graph shown in Fig. 3 highlights the bottleneck areas for this mock line. In Fig. 4, any process units with maximum achievable line speeds much higher than the overall bottleneck speed have been removed for clarity.

Figure 5

Continuous paint line simplified graphical output with oven upgrades.

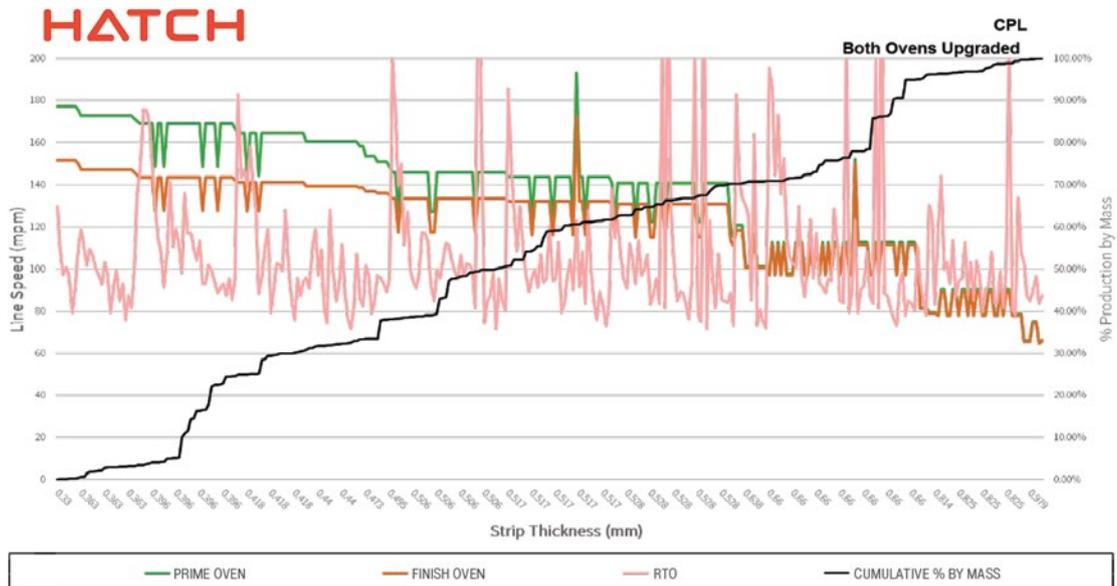
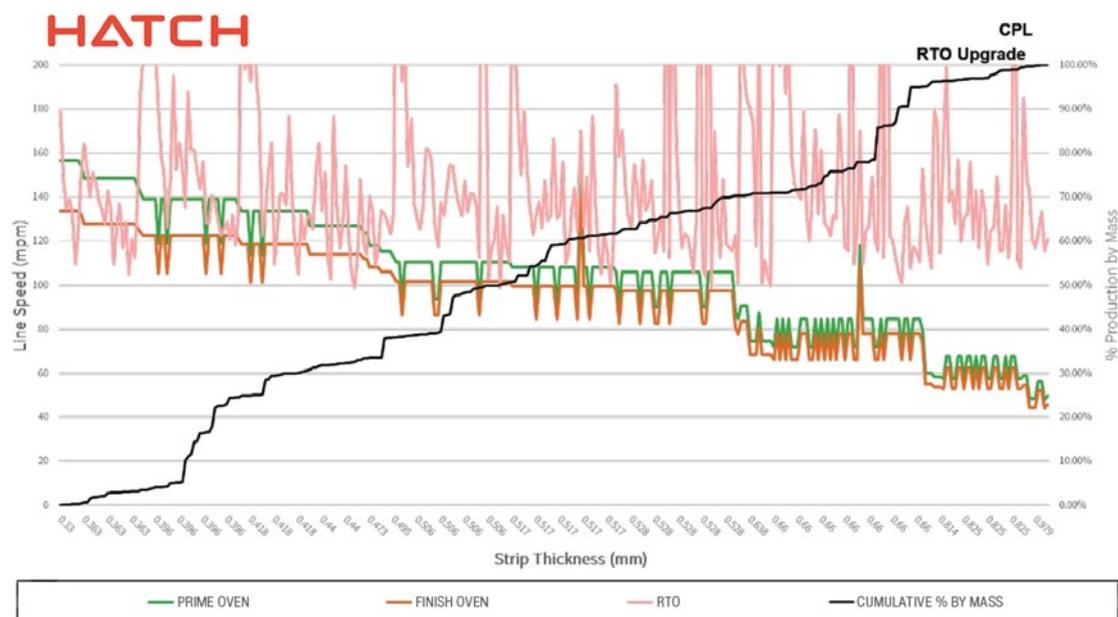


Figure 6

Continuous paint line simplified graphical output with RTO upgrades.



The lowest line speed shown at each product thickness represents the maximum theoretical achievable line speed for the overall line for that product, with the corresponding process unit acting as the bottleneck. As stated earlier, the RTO in this case is typically the bottleneck at lighter gauges, with the finish oven becoming the bottleneck at heavier gauges. Additionally, the prime oven typically follows the same trend as the finish oven, meaning it has a similar maximum achievable line speed.

Because this product mix shows a relatively even distribution between light and heavy gauge, it may make sense to target the areas that pose a bottleneck to heavy-gauge products first, as they will have a greater effect on the overall production tonnage. Here, options to upgrade the finish oven could be to replace the burners to increase the heat transfer capability of the oven or extend the oven by an additional unit if space allows. Per the graphical output, the simulated prime oven results show that it is limited at a similar speed to the finish oven, so it would be most effective to upgrade both ovens at the same time. If both ovens are upgraded to address bottlenecks, a production gain of 7.6% can be achieved. Fig. 5 shows these simulated upgrades.

The other major bottleneck experienced by this mock line is the RTO, which is particularly prevalent in the light-gauge products. The RTO module is set up to determine line speed limits based on operating temperature limits (which can be fatal to equipment if exceeded), and solvent loading requirements by permit (in mass flow of VOCs). If the RTO is removed as a bottleneck instead of the ovens, a production increase of 8.2% over the base

case could be achieved. Fig. 6 is the same graph as Fig. 5 if the RTO was debottlenecked instead of the ovens.

In many cases, concurrent upgrades in separate process modules can result in synergistic capacity gains exceeding the sum of the individual improvements. For example, if both ovens and the RTO were upgraded, a capacity gain of 26.4% over the base case could theoretically be achieved. In some cases, the upgrades could be phased such that the improvement from one would be used to fund the improvement of the next upgrade. Fig. 7 illustrates this scenario.

To further illustrate the benefits of debottlenecking process units on a line, Fig. 8 shows the original maximum achievable line speed compared to the theoretical maximum achievable line speed after the simulated equipment upgrades.

In order to achieve an even greater production increase, a subsequent 10% reduction in total downtime can further boost overall production by an additional 5.5%. Opportunities to reduce downtime can be provided based on Hatch experience and benchmarking against best-in-class operations after delay log analysis and review of scheduled maintenance downtime.

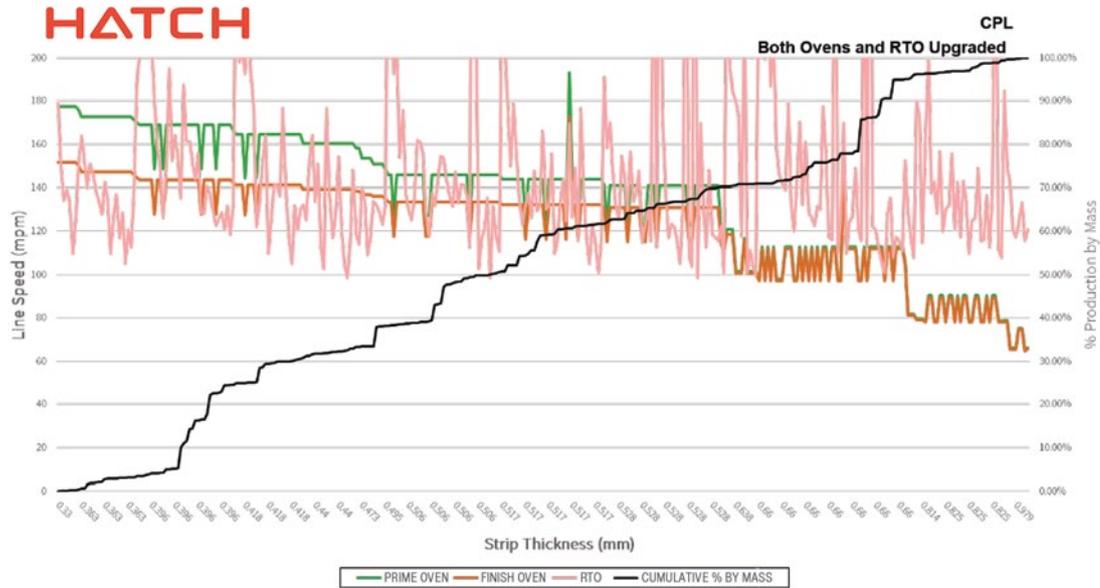
Table 1 provides a summary of the main bottlenecks observed during the analysis of this mock paint line and a list of potential upgrades for each area.

Case Study – Galvanizing Line

By contrast, the output graph from analyzing the mock galvanizing line shows that many furnace, cooling and terminal equipment sections have similar bottleneck

Figure 7

Continuous paint line simplified graphical output with oven and RTO upgrades.



speeds. In Fig. 9, process areas that are unlikely to pose a bottleneck have been removed for clarity.

In order to fully debottleneck the process areas shown in Fig. 9, costly and impractical improvements, such as complete replacement of the furnace heating and cooling zones, would be necessary. If simpler, more cost-effective solutions, like those included in Table 2, were implemented to upgrade the furnace cooling, upleg cooling, RTF, both accumulators and exit overspeed, a production

increase of 10.3% may be achieved. In this case, pairing a moderate set of equipment enhancements with an operating hour increase of about 7% allows for a potential 18.7% production increase over the base case. This example illustrates the fact that sometimes it may be more cost-effective to target downtime improvements rather than undertake multiple large-scale capital replacements.

Figure 8

Continuous paint line maximum achievable line speed baseline compared to upgraded.

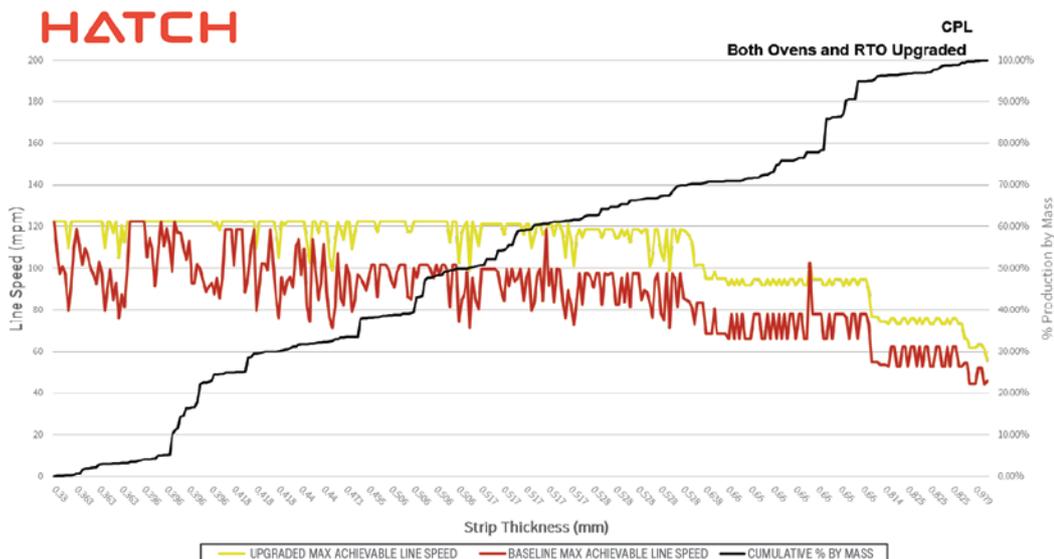


Table 1

Potential Continuous Paint Line Upgrades for the Mock Line Bottlenecks

Bottleneck area	Possible upgrade	
Regenerative thermal oxidizer (RTO)	Prevent overheating by repowering fans or changing damper positions to increase dilution airflow	
	Reduce heat loss needed for combustion by replacing heat retention media with one that has a higher heat capacity (i.e., different refractory materials and thicknesses)	
	Reduce heat loss needed for combustion by using waste heat from the furnace to preheat air into the RTO	
Prime/finish ovens	Install burners with higher ratings to increase maximum zone temperature	
	Improve convective heat transfer by replacing nozzles with better impingement	
	Increase burner efficiency by preheating combustion air with waste heat	
	Improve heat transfer by recycling waste heated oven air	
	Increase oven length to be able to increase line speed while maintaining required dwell time to achieve peak metal temperature	
	Reduce lower explosive limit levels by increasing airflow through ovens	
Operating hours	Reduce paint changeover time by installing dual coating heads	
	Reduce paint changeover time and oven temperature adjustment time by scheduling campaigns of similar products	
	Reduce downtime due to common unplanned maintenance events by increasing scope of preventive maintenance program	
		Reduce oven temperature adjustment time by adding variable speed drives to oven fans

Table 2 summarizes areas targeted for improvement for the mock galvanizing line and potential upgrades for each.

Model Applications

While this article focuses on continuous galvanizing and paint lines, this debottlenecking approach is readily applicable to other process lines. Because each model component can be enabled or disabled independently, the debottlenecking approach can be customized for nearly any continuous process line. New functionalities can also be introduced if necessary; for instance, a recent project necessitated analysis of the

Figure 9

Continuous galvanizing line simplified graphical output.

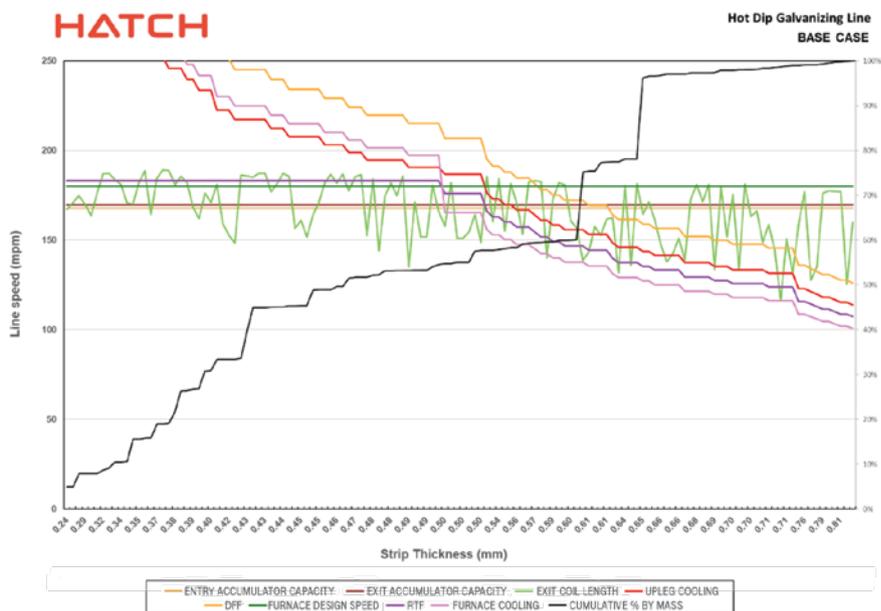


Table 2

Potential Galvanizing Line Upgrades for the Mock Line Bottlenecks

Bottleneck area	Possible upgrade
	Improve convective heat transfer by replacing nozzles with better impingement
	Improve heat transfer by increasing hydrogen content in the cooling atmosphere
Jet cooling	Improve convective heat transfer by increasing fan power, volume or pressure of the gas
	Decrease jet cooling atmosphere temperature by replacing heat exchangers with more efficient type
	Decrease cooling water temperature entering the heat exchangers by upgrading the cooling tower
Upleg cooling	Improve convective heat transfer by replacing nozzles with better impingement
	Improve cooling capacity by adding water cooled rolls or additional cooling zones
Radiant tube furnace	Restore heating capacity by replacing any damaged tubes
	Improve heat transfer by increasing hydrogen content in the furnace atmosphere
	Improve heat transfer by replacing tube types with more efficient design (e.g., “U” shape tubes)
	Improve heat transfer by applying high-emissivity coatings to the radiant tubes
	Tune burners to ensure full combustion if gas-fired or consider more efficient burner types
	Implement a program of regular maintenance to ensure good working condition of the tubes
Accumulators	Increase capacity by extending accumulator height or length if space permits
	Increase capacity by reducing roll size enough to add additional strands to existing accumulator structure
Exit section changeover time	Reduce changeover time through software changes or mechanical drive upgrades to increase mandrel overspeed
	Reduce changeover time by decreasing length of sample section and tail section that is cut at end of coil
Operating hours	Reduce downtime of planned maintenance to frequency of industry proven norms (e.g., reduce sink roll changes to every 30 days if they are occurring more frequently without wear issues)
	Reduce furnace transition time by scheduling campaigns of similar gauge products
	Reduce downtime needed for furnace inspection requirements by ensuring minimal scale build-up occurs in the furnace from oxygen ingress
	Reduce downtime due to common unplanned maintenance events by increasing scope of preventative maintenance program (e.g., regular cleaning of heat exchangers)

RTO capacity of a paint line, and at the time, a module to do this did not exist in the model. However, the Hatch team was able to input the process information provided by the client into a first-principles approach to thermodynamically model the RTO and create a new module.

Beyond expanding capacity for the same product mix, the model can predict throughput for a new proposed product mix without occupying valuable production time

for trial runs. Instead of using existing production data to adjust equipment capabilities to remove bottlenecks, a projected product mix can be fed into the model with existing equipment parameters to show how production volumes would be affected. Similarly, the model can be used to identify new equipment requirements necessitated by a change to the product mix.

The model itself can transcend the evaluation of a process line at a particular point in time. It can also be adapted to act as a digital twin to predict bottlenecks based on real-time data inputting and troubleshoot live to improve reliability and production.

The debottlenecking model can also be used to facilitate carbon emissions analysis, allowing steel producers to evaluate the effect of upgrades on Scope 1 emissions. This is critical in today's manufacturing landscape, where reducing greenhouse gas emissions and meeting regulatory standards are top priorities. By using the same operating data and heat transfer fundamentals that allow the model to calculate a maximum line speed, emissions levels can be calculated and can help guide the selection and prioritization of various product mix changes or proposed equipment upgrades. Additionally, this same information can be used to analyze the permitting impacts of operational or equipment changes.

The debottleneck modeling process is an example of technical operational improvement assessment and can be part of broader business transformation programs. The recommendations from the model can be leveraged into both production improvement and cost savings initiatives for implementation in a Project Management Office (PMO) program. Support during the comprehensive transformation engagements include full engineering services and management operating system optimization to cover all aspects of the business and ensure timely and cost-effective implementation or recommendations.

Conclusions

A robust debottlenecking model offers steel producers critical insights into existing process limitations and pathways for performance enhancements. By combining historical data, equipment specifications and operational constraints within modular Excel-based software, it's possible to pinpoint and prioritize improvement opportunities. In tandem with holistic planning for quality, production scheduling and environmental targets, model-based debottlenecking ensures that improvements are both technically sound and financially viable. As steel producers face increasing pressure to optimize throughput while managing costs and reducing emissions, such computational modeling approaches will remain a cornerstone of continuous improvement and sustainable operations. ♦

This article is available online at AIST.org for 30 days following publication.



This paper was presented at AISTech 2025 — The Iron & Steel Technology Conference and Exposition, Nashville, Tenn., USA, and published in the AISTech 2025 Conference Proceedings.

AISTech Booth: 637



Refractory / Dry Cast Mixers ranging from 300—3000+ lb. capacities.

Durable, Efficient, Uniform Mixing & Delivery.

EZG Elevates Refractory Solutions: Introducing the NEW HPMC Line.



[LEARN]
MORE

EZG Hog Pump Mixer Combo units are uniquely crafted for dense refractory shotcrete and pump cast applications, this powerhouse combo integrates a high-torque pan mixer with an ultra-high-pressure piston pump.



1-740-224-8084 / ezgmfg.com

EZG Manufacturing is a division of EZ Grout Corporation. All EZG Manufacturing products are backed by our **two-year warranty** on parts unless otherwise stated.

©2024 EZG Manufacturing. 00887 AIS MAR-2026

