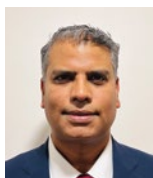


Implementation of Automated Alternate-Gauge Diversion at Burns Harbor Hot Strip Mill: Results and Benefits in Terms of Its Impact on Reject Reduction and Stable Operation



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Digital technologies are transforming industry at all levels. Steel has the opportunity to lead all heavy industries as an early adopter of specific digital technologies to improve our sustainability and competitiveness. This column is part of AIST's strategy to become the epicenter for steel's digital transformation, by providing a variety of platforms to showcase and disseminate Industry 4.0 knowledge specific for steel manufacturing, from big-picture concepts to specific processes.

Even the most advanced and well-maintained hot strip mills (HSMs) are susceptible to operational disruptions, such as cobble events or roll mark issues, further leading to schedule delays. Post operations restart, the mill may need to adjust its schedule to produce coils at a heavier gauge than ordered, in order to not jeopardize the stable operation of the mill. However, manual changes to the product data input (PDI) values for these alternate orders are time-consuming and often impractical. The resulting coils, if rolled at heavy gauge without an appropriate order, frequently become rejects, adding to the already significant production losses.

This article presents a solution to mitigate this problem. By overlaying alternate order data onto the next coil to be produced, a good coil was created on the alternate order. This approach significantly reduced the number of rejects in the mill and improved overall productivity. The implementation details are described in the article, along with the benefits and lessons learned from this project.

Introduction

The Burns Harbor HSM is a flagship hot mill designed to produce light-gauge class-1 exposed hot roll material within Cleveland-Cliffs' footprint. There could be significant challenges during production

of exposed quality light-gauge hot roll material if the mill becomes unstable or incurs unplanned stoppages during a rolling schedule.

The work outlined in this article showcases how a new system finds appropriate orders that fit hot rolling scheduling constraints and saves on prime product yield during those situations. The core logic of the program was jointly developed by the HSM Quality, Operations and Process Automation group. Specifically, this work showcases how different strategies can be deployed during a light-gauge rolling campaign when unplanned stoppages occur and help the operations to get out of the mill instability without producing coils that are outside the approved orders.

Problem Definition

A hot mill that is not coupled with a thin-slab caster charges slabs at room temperature to reheat furnaces; such HSM typically follows a "coffin" shape schedule for their operational lineup. A notable constraint of these scheduling arrangements is that these lineups follow strict scheduling guidelines where large stepdown changes in gauge occur from one bar to the next and increases in width are not allowed between consecutive bars.¹ New lineup schedules generally start with fresh set of rolls on all seven finishing stands and a key aspect at the start of a coffin schedule is the

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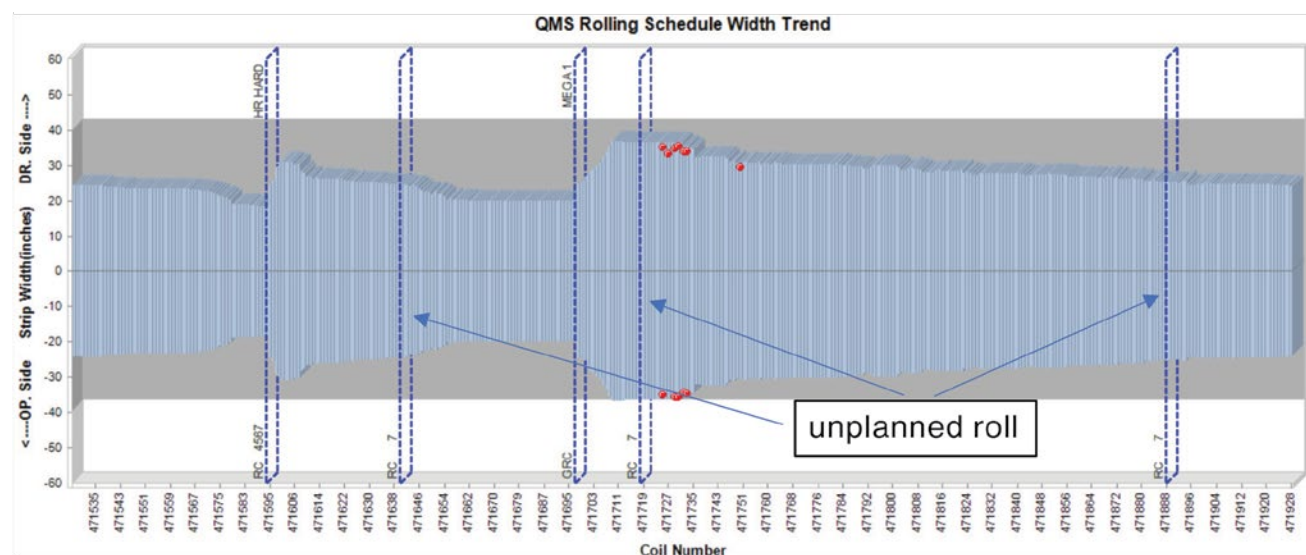
warm-up section (i.e., heavier-gauge bars are rolled in this section). The warm-up section helps in building the roll thermal puff and also helps in leveling the mill. A key underlying assumption with these scheduling guidelines is that no delays will occur between the bar production. Any extended unplanned downtime and continuous cooling of the rolls during this downtime results in a loss of roll thermal puff that was obtained during the warm-up section. Furthermore, if one or two sets of rolls are replaced during a delay, due to issues such as roll marks on the strip or due to poor shape, then it can potentially affect the leveling in the mill, further exacerbating operational challenges. If the aforementioned events do occur at a point in the coffin schedule where rolling gauge was on the extreme light side (<0.09 inch), then it adds even more difficulty during threading and tail-out of the bar. In the old system, to get out of such situations, the only option operators had was to select a thickness that was easier to roll. The system had a predefined menu where an operator pressed a button on the human-machine interface (HMI) and was offered three standard gauge options: 0.13, 0.177 and 0.210 inch. This option only offered the operator the choice of a higher gauge without indicating if orders for these preset gauges were available or not. Furthermore, there were also no controls in place to govern the final product's width, finishing/coiling temperature, as well as ability to enforce strict gauge and width tolerance requirements. Consequently, many of these affected products ended up being rejected internally for quality or being diverted and thus being sold on the secondary market at discounted prices. This further results in delayed sales of these products and is often at a loss for the company.

Methodology

Hot rolling is probably the fastest conversion process in the steel business wherein practically unique product types can be produced at a very fast pace within one schedule. Even the slabs from the same heat lot may be used for entirely different products because there could be differences in product characteristics such as gauge, width, customer, tolerances, mechanical properties requirements, etc. These product characteristics and other input conditions do come in the form of PDI to the HSM level 2 computer, which then assigns these inputs to various sections of the mill or to the slab/transfer bar as inputs during the conversion process of slab to a coil. A PDI therefore is largely dependent upon the customer order; thus making changes to one variable of PDI at a time during a running schedule is almost an impossible task. Changing the gauge of a coil to a higher gauge and ensuring the resulting product still fits the final order requirement requires more than just changing the gauge, it requires existing PDI to be overwritten with the most important fields on the PDI of the alternate order before the slab is discharged from the furnace. Overlaying alternate-order PDI values onto the slab before it turns into the coil will ensure that the resulting coil requires minimal manual intervention after it is produced. Now, the next challenge for the team was to identify those important fields of the PDI for all the open and dressed orders in the business system for the orders that have any melt demand. Melt demand is the tonnage for an ordered grade at a specific width that is required to be cast by the slab casting area. Important PDI fields for every hot rolling entity could be different, as each hot mill facility and

Figure 1

Coffin shape schedule illustrating intermediate roll change, full 7-stand roll changes and unplanned f7 only roll changes.



their order dressing requirements are unique in many aspects. For the Burns Harbor hot mill, the project team outlined the following as critical PDI fields:

- Melt Grade: ensures the exact same grade orders are swapped.
- Melt Demand (tons): ensures that only orders that have some casting demand will be used for swapping.
- Order Number: ensures that the coil produced gets assigned onto the correct order and melt demand.
- Aim Gauge: ensures the right gauge is produced.
- Aim Width: ensures appropriate spread squeeze rules are applied to the slab and the final width is made.
- Finishing Temperature: ensures correct finishing mill setup.
- Coiling Temperature: ensures correct runout table spray setup and best shot at getting coiling temperatures.
- Gauge Tolerance: ensures gauge stays within the tolerance.
- Width Tolerance: ensures product width is within the width tolerance.
- Surface Exposure Requirement: if an alternate order is for an exposed quality product, then best practices are automatically followed.
- Mechanical Testing: ensures a test flag is put on the coil and the coil is not going to be shipped without the prerequisite tests.
- Sulfur Limits and Calcium Treatment Flag: ensures the correct sulfur levels and inclusion modification practices were followed in the slab.

To facilitate the implementation of alternate-gauge programming in the level 2 system, the quality team was entrusted with developing an order information table that could be retrieved from the business system. An example row from this order table is shown in Fig. 2. Given that the level 2 system lacks direct access to the level 3 business system, running queries across the 50 relevant tables each time a bar is discharged from the furnace was deemed impractical. Not only would it lead to significant delays in processing, but it would also compromise the performance of the level 2 system. To address these limitations, a static order summary table was created within the level 2 system using stored procedures. The procedure runs every 4 hours to update the melt demand for all orders in the system. Meanwhile, during the 4-hour window between the updates, the level 2 system continuously tracks melt demand by subtracting the weights of swapped alternate orders, thereby preventing the production of coils that may potentially exceed the allowable order limit.

The following design constraints/challenges were given to level 2 team:

1. Overall steps to using an alternate gauge program should be very easy for the operators to adopt to ensure its success.
2. If an operator changes their mind at any point during the process, they should have the ability to cancel the alternate order until the point at which the slab has not been discharged from the furnace and revert to the original planned schedule.
3. Level 2 models (roughing mill, finishing mill, coiling temperature control, etc.) should process the alternate-gauge coil in a way that would ensure all final order parameters are met.
4. Melt demand for both parent and child orders should be adjusted dynamically once the produced coil goes onto alternate order so that the caster group does not overproduce the slabs for the alternate order but produce one for the not-produced order.

The following design constraints/challenges were given to the quality team:

1. Ensure minimal review process by the quality disposition engineer after the coil was produced through the alternate gauge order.

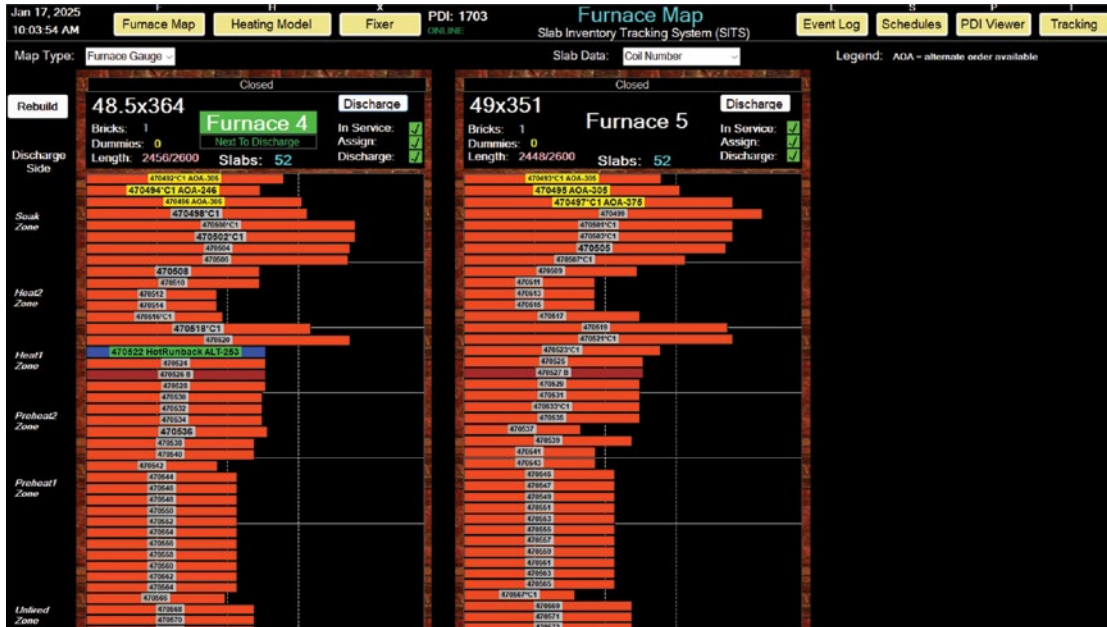
Figure 2

Order information table showing example row item.

	Row #12
Mill_Order	80110170
SPLIT	49
Grade_final	H 205
SECOND_ALPHA	H
Melt Demand	22
HM_BAND_GAUGE	0.1
HM_BAND_WIDTH_FRACT	710308
HmrW	71.36
FINISH_COIL_TEMP	C/L
MET_TEST_CODE	GXXXXX
Gauge_Tol_Total	0.008
spec_code	9817
PROCESS_CODE	P08
MILL_PRACTICE	[NULL]
dt	2024-08-12 12:00:05.850
productClass	2
WIDTH_TOLERANCE	516
WIDTH_TOL_DEC	0.3125
widthNeg	71.20375
widthPos	71.51625
hrc	0

Figure 3

Schedule rehear furnace map layout of slabs, next to discharge slabs are showing at the top.



2. Coil flow until it ships to the customer should not require any manual intervention or require any extra process steps such as overwidth adjustment, etc.

3. Alternate orders cannot be for secondary orders or stringer coil orders; they must be assigned only for prime customers in order to not count them toward reject numbers.

Figure 4

Example product data input (PDI) of a slab and selection of Alt-Order on the bottom left.

Modify PDI

PDI (database): OK Modify PDI for RSN# 023050-01 ShortSeq: 0 Schedule: 2-MEGA 2
PDI (form): - Wk/Yr: 0225 Recv Order: 69 Mill Order: 540001 Bar State: Charged

SEQ	BAR	pdiErrors	SYSQNO	SCH	Ingot	Cut	Heat	Grade	IFSteel	HF	Length	Width	Thick	Weight	Weight2	Mprc
23050	1	0	185450	2	05	A	813K71300	IP127XD		11	364	48.46	10	48920	A	H

BRN	LUC	HMRG	HMRW	GLTP	GLTN	WTLT	WTLN	MNFT	F_TEMP	F_CODE	MNCT	C_TEMP	C_CODE	MXCT	MON	DCT
1	279	48.94	11	11	0.56	0.56	1600	1625	E		1150	1160	J	1200		0

PROCO	CLAS	D_CD	D_ORD	D_IT	C_CD	END_CUST	DEST	TST	ORD_GRD	O_GAG	ORD_WID	WKS
100	1	838	31932	01	STL-	STL-WCO	3N		ZQ328CD	2710	480308	0

spdSqz	coilerPIW	DSP	Brick	FCE	COILNO	BBand	PQ	QA	TMGAG	Schedule	SchCode	trackBar	hotRB	dltP	dltPThk
0.479999542	999.5914			4	470492			N	0.0653	MEGA 2	38		0		2

C	Mn	P	S	Si	Cu	Ni	Cr	Sn	Mo	V	Ti	Al	Cb	N	B	Co	Pb	As	Zr	W	Mg
0.0961	0.48	0.012	0.003	0.016	0.013	0.01	0.02	0.001	0.003	0.001	0.002	0.046	0.002	0.0045	0.0002	0.002	0	0	0	0	0

R5Temp	fceTemp	MOP	Item	ProdCod	PaintHR	UniITM	CM Week
1927	2249	B088		2-			

pdiRecv Table (Data from IMS):

fTemp	cTemp	rollingSequenceNo	scheduleNo	createDateTime	updateDateTime	updateCtr	rawPDI	transCode	recType	recPos	recID
[E] 1625	[J] 1160	2305001	2	1/3/2025 11:3...	1/6/2025 5:50...	2	HLF14B32 D2...	HLF14B32	D	2	SLAB

Original Order: 838-31932-01 IP127XD
IMS: 279 48.9 1127 [E] 1625 [J] 1160
Alt Order
SITS: 279 48.9 1127 [E] 1625 [J] 1160

Click in the text box of the PDI field you want to change.

Changes only happen AFTER the "ACCEPT" button is pressed

Track RSN #1 Clear #1
Furnace Map Tracking
Track RSN #2 Clear #2

Gray = Field is NOT editable White = Field is editable

Make changes above to one or more PDI fields.

Accept Changes Close

STEP 1 STEP 2 STEP 3

Figure 5

Display list of available orders for selection once Alt-Order button is pressed.

Modify PDI

PDI (database): OK

Modify PDI for RSN# 023050-01

ShortSeq: 0

Schedule: 2-MEGA 2

PDI (form):

Bar State: Charged

SEQ	BAR	pdiErrors
23050	1	0

BRN	LUC	HMRG
	1	279

PROCO	CLAS	D_CD
100	1	838

spdSqz	coilerPIW
0.479999542	999.5914

C	Mn	P	S
0.0961	0.48	0.012	0.00

R5Temp	fceTemp
1927	2249

pdiRecv Table
(Data from IMS):

Original Order: 838-31932-01

IMS: 279 48.9 1127

Alt Order

SITS: 279 48.9 1127

Alternate Orders for Coil #: 470492

RSN#: 023050-01 SYSN#: 185450 FCE: 4 Grade: I127

Order: 838-31932-01

Grade2:P

Alternate Order Modifies these PDI Fields: Maroon-Current (SITS)

Gauge: 279 Width: 48.9 FTemp: 1625 CTemp: 1160

+11/-11 +0.56/-0.56 [E] 1600 [J] 1150-1200

MillPracticeCode: H ProcessCode: 100

Order#	Grade	Gag	Wid	F/CTemp	MPC	PCode	Class	Grd2	Tons
897-30168-01	I127	305	49.2	E/J		100	2	Q	92
833-52055-01	I127	249	48.6	F/J	H	100	1	Q	40
833-53076-01	I127	185	48.6	F/J	H	223	1	Q	40

Close

Click CLOSE button to close this window and cancel any changes

Figure 6

Once Alt-Order selection is made, PDI is overwritten and Alt-Order button shows red text.

Modify PDI

PDI (database): OK

Modify PDI for RSN# 023050-01

ShortSeq: 0

Schedule: 2-MEGA 2

PDI (form): -

Wk/Yr: 0225 Recv Order: 69 Mill Order: 540001

Bar State: Charged

SEQ	BAR	pdiErrors	SYSQNO	SCH	Ingot	Cut	Heat	Grade	IFSteel	HF	Length	Width	Thick	Weight	Weight2	Mprac
23050	1	0	185450	2	05	A	813K71300	IP127XD		11	364	48.46	10	48920	A	H

BRN	LUC	HMRG	HMRW	GTLF	GTLN	WTLF	WTLN	MNFT	F_TEMP	F_CODE	MNCT	C_TEMP	C_CODE	MXCT	MON	DCT
	1	249	48.56	9	9	0.56	0.56	1600	1625	F	1150	1160	J	1200	0	0

PROCO	CLAS	D_CD	D_ORD	D_IT	C_CD	END_CUST	DEST	TST	ORD_GRD	O_GAG	ORD_WID	WKS
100	1	833	52055	01	STL-	STL-WCO	3N		ZQ328CD	2710	480916	0

spdSqz	coilerPIW	DSP	Brick	FCE	COILNO	BBand	PQ	QA	TMGAG	Schedule	SchCode	trackBar	hotRB	dltP	dltPThk
0.479999542	999.5914			4	470492			T	0.0653	MEGA 2	38		0	2	

C	Mn	P	S	Si	Cu	Ni	Cr	Sn	Mo	V	Ti	Al	Cb	N	B	Co	Pb	As	Zr	W	Mg
0.0961	0.48	0.012	0.003	0.016	0.013	0.01	0.02	0.001	0.003	0.001	0.002	0.046	0.002	0.0045	0.0002	0.002	0	0	0	0	0

R5Temp	fceTemp	MCP	Item	ProdCod	PaintHR	UnitTM	CM Week
1927	2249	B088		2-			

pdiRecv Table
(Data from IMS):

fTemp	cTemp	rollingSequenceNo	scheduleNo	createDateTime	updateDateTime	updateOr	resPDI	transCode	resType	resPos	resID
[E] 1625	[J] 1160	2305001	2	1/3/2025 11:3	1/6/2025 5:50	2	HLF14832 D2	HLF14832	D	2	SLAB

Original Order: 838-31932-01 IP127XD

IMS: 279 48.9 1127 [E] 1625 [J] 1160

Alt Order: 833-52055-01

SITS: 249 48.5 1127 [F] 1625 [J] 1160

Click in the text box of the PDI field you want to change.

Changes only happen AFTER the "ACCEPT" button is pressed

Track RSN #1 Clear #1

Furnace Map Tracking

Track RSN #2 Clear #2

Make changes above to one or more PDI fields

Accept Changes

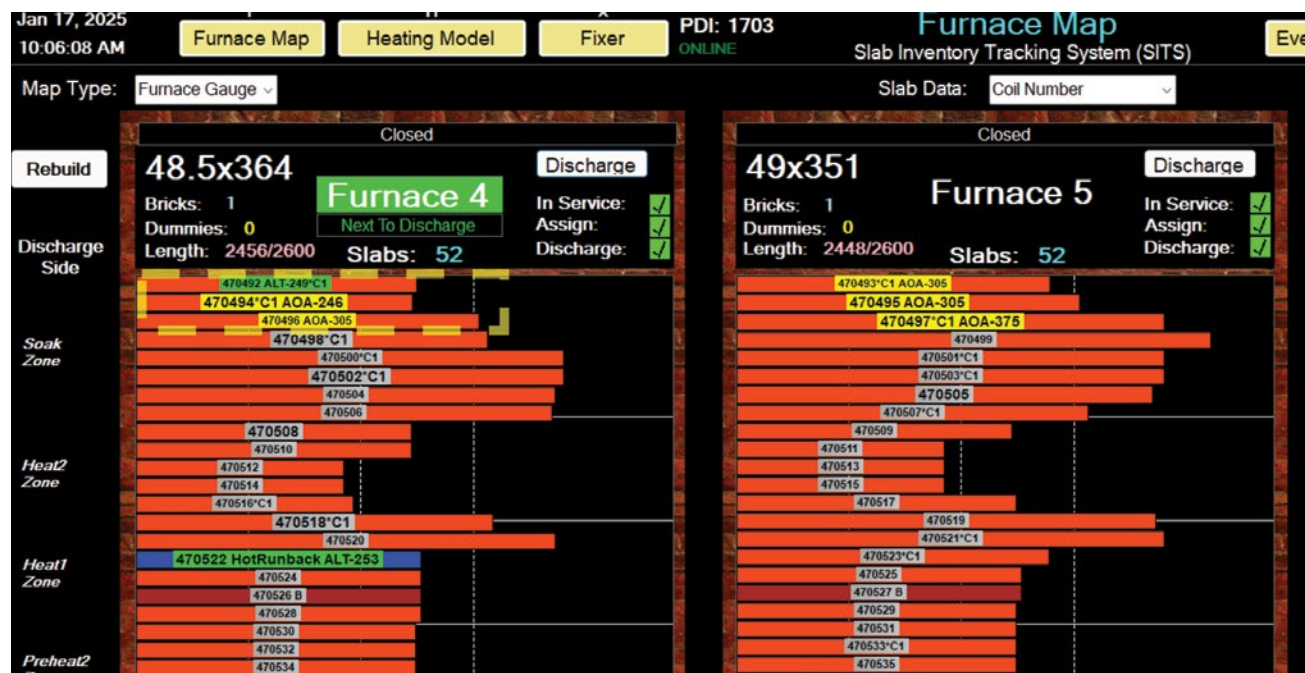
Close

STEP 1 STEP 2 STEP 3

Set 023050-01 (279x48.9) to alternate order 833-52055-01 (249x48.6)

Figure 7

Next to discharge slab from furnace 4, in the dashed border area, shows Alt-Order was selected. The slab color changed to green text box.



Figs. 4–7 illustrate the steps involved in selecting one slab from furnace 4, which is next to discharge and was later selected for the alternate order. Once the next discharge bar from furnace 4 is clicked for options available, it then displays three orders are available, as shown in Fig. 5. The operator can choose the most appropriate option from the available choices. Upon confirming the alternate order for a particular slab, as shown in Fig. 7, the corresponding slab's color on the HMI was updated to a green box for improved visibility and easier identification. Using a total of five mouse clicks, an operator was able to choose the slab for the appropriate alternate order and save it from being rejected.

Fig. 8 shows the alt-gauge usage trends from March 2023 to June 2024 when an alternate-gauge program was first implemented. During this phase of implementation, the team realized the challenges associated with regard to its adoption by the operators. Alt-gauge usage ranged anywhere between 25 and 70% due to several missed opportunities in certain months because operators simply forgot to check for the alternate-gauge prior to doing the gauge diversion.

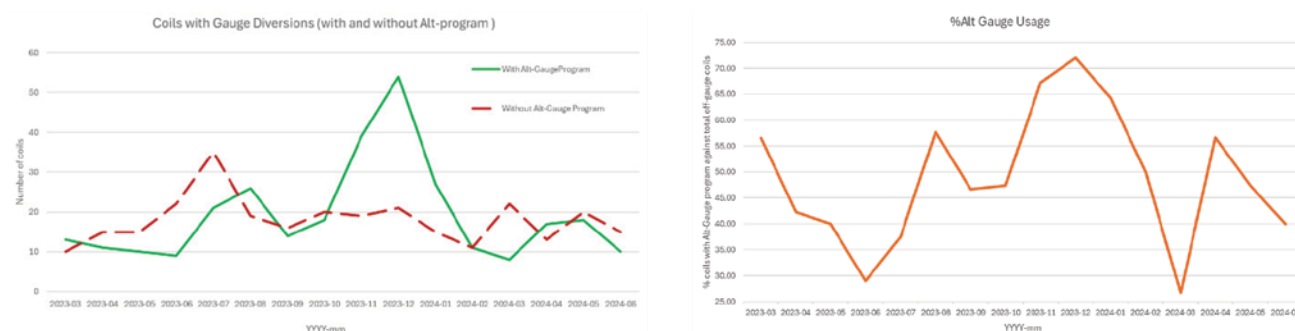
Steps Taken to Improve Adoptability

The following steps were taken to improve overall adoption from operators:

1. Dectalk alarm after long delays if next to roll material is below 0.10 inch:
 - This relatively simple upgrade turned out to be very effective as it allowed the operators to focus on performing operational checks rather than looking for an alternate order prior to restarting. A simple Dectalk would bring their attention to the alt-gauge option.
2. HMI to display alternate orders information on the six slabs closest to the discharge end on the furnace map:
 - This upgrade also proved to be a very useful tool as it helped operators by eliminating the need to click each bar, which would adversely affect their interest and morale to use this tool if no orders were available after clicking through each and every bar just prior to resuming operations after a long delay.
3. The option to assign run-back of slab, in rare cases, when there are no Alt-Orders available or when it is difficult to roll to a light-gauge coil.
 - If for some reason the option for Alt-Order was not available for the next bar in the

Figure 8

Gauge diversion trends using with and without Alt-Order program.



discharge sequence but the same was available for the bar after that, it was decided to allow operators to run back the bar that doesn't have the order. The team was able to integrate the runback option within HMI to facilitate this functionality.

4. Use of Alt-Orders to cut into schedule:
 - This feature is also being used more recently for cutting into schedule before and after a planned downtime to further allow some flexibility for the scheduling group.
5. Daily email reporting for management review:
 - A daily summary of all the gauge diversion slabs is being sent to management for further review with the operators for any missed opportunity. The email report, shown in Fig. 10, displays two tables; the top table

shows gauge diversion using Alt-Orders and the bottom table shows the gauge diversions done without using Alt-Orders. The bottom table also indicates whether alt gauge options were queried and were available at the time. This helps the management team to engage with the operators and help facilitate the usage of this tool or identify improvement opportunities.

Fig. 11 illustrates significant improvement in operator adoption after July 2024; the team was able to consistently hold the % alt-gauge usage above 65%.

Results

This tool has proven to be immensely effective in providing operators with the ability to tactically mitigate quality diverts because of unplanned delays while improving the

Figure 9

Illustrates in bordered dashed yellow section next to discharge top three slabs in each furnace to indicate whether Alt-Orders are available on them without having operators to click on each of these slabs.



Figure 10

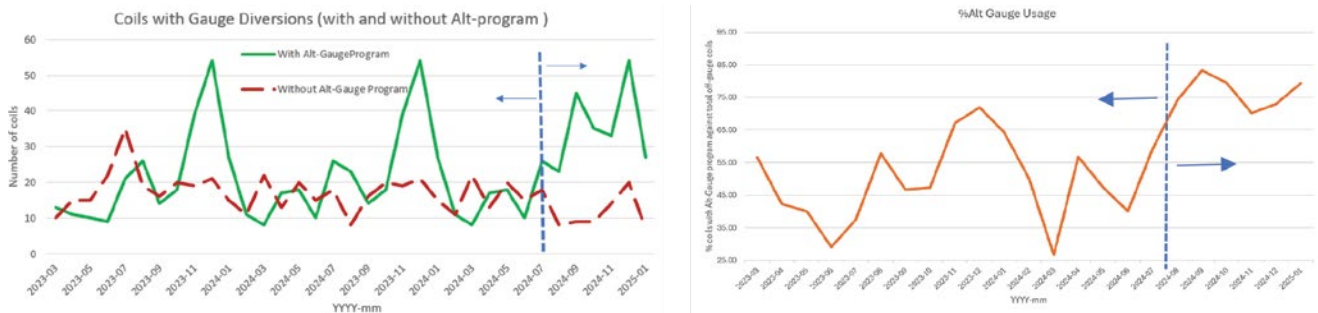
Summary of daily email report to show any missed opportunity for gauge diversion.

Alt-Gauge Orders Produced Yesterday									
coil slabid	sysqno	furnaceDischargeTime	Original-Order	Alt-Order	dispositionCode	vdsApplied	f7AimGauge	f7AimWidth	
466931	821K1023051A	232201	2024-12-29 21:59:21	881-30755	881-30759	99	69.....	0.177	72.75

Alt-Gauge Orders NOT used Yesterday										
coil slabid	sysqno	furnaceDischargeTime	Order_Final	dispositionCode	vdsApplied	f7AimGauge	f7AimWidth	Op_looked_options	Alt_Ord_Available	
466799	842K4230055A	418677	2024-12-29 16:20:55	853-30494	99	69.....	0.185	60.75	NA	Y
466800	833K6944003A	384454	2024-12-29 16:23:46	853-30494	99	69.....	0.130	60.75	NA	NA
466821	833K6528004A	382065	2024-12-29 17:07:31	807-51154	99	69,10,38.....	0.175	52.32	NA	Y
466822	842K4206054A	418531	2024-12-29 17:10:32	844-50219	99	69,38.....	0.175	52.32	NA	Y

Figure 11

Improvement of operator adoption before and after level 2 human-machine interface changes and incorporation of additional management review.



overall quality performance. Since its implementation from March 2023 to January 2025, the team successfully applied 550 alternate-gauge options amounting to US\$1.75 million of savings for the company.

Conclusions

The work outlined in this article shows how the Burns Harbor Quality, Operations and Automation groups worked together and solved a real-life problem without any capital investment. The new capability has helped

reduce off-gauge rejects and has given operating group flexibility to run the rolling mill in stable mode.

Disclaimer

Due to the unique and plant specific nature of the work presented in this article, it was not possible to identify relevant reference literature specific for minimizing rejections associated with gauge diverts. The findings and improvements reported here are relevant for Cleveland-Cliffs Burns Harbor hot strip mill.

Reference

1. N. Torres, G. Greivel, J. Betz, E. Moreno, A. Newman and B. Thomas, "Optimizing Steel Coil Production Schedules Under Continuous Casting and Hot Rolling," *European Journal of Operational Research*, pp. 496–508. ◆



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