PRODUCTIVITY INCREASE AT ARCELORMITTAL TUBARAO HSM *

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Abstract

This project involved a teamwork including process control, maintenance and operation specialists, R&D and CTO experts to identify and actuate on each opportunity to increase charging temperature, furnace efficiency, decrease discharging temperature when possible, decrease FM and RM cycle time (mainly speed increase and interpass time decrease), tracking zones optimization, safe use of equipment power limits, safety interlocks revision and tune models for Mill Pacing Control and Slab Design.As result of these efforts, ArcelorMittal Tubarão HSM today occupies a prominent position among the best HSM of similar layout and produced mix of the group and worldwide. This paper will show the path which was followed by the AMT HSM team to achieve more than a 20% productivity increase resulting in a hot coils production per year more than 700 million tons higher.

Keywords: Hot rolled coils; Productivity

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1 INTRODUCTION

AMT Hot Strip Mill, as showed in figure 1, is constituted of two reheating furnace, a rougher mill, a coil Box, a finishing train, a cooling system and two downcoilers.

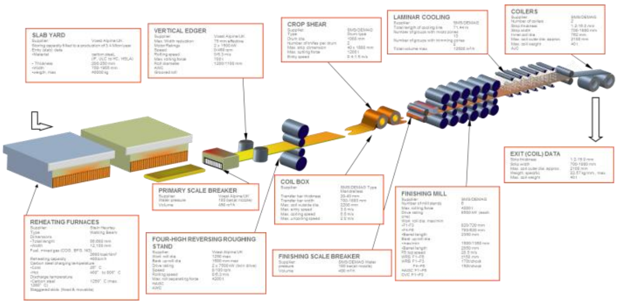


Figure 1. ArceloMittal Tubarão Hot Strip Mill Layout.

After being hot-rolled, the coils may be shipped directly to the customer or undergo further processing steps still in Tubarão finishing lines, Coil Division Line and Hot Skin Pass Line, or be shipped to Vega unit, located in the south of Brazil, to be transformed into cold-rolled, galvanized and coated products.

Product mix includes Low/Medium Carbon, High Carbon and Ultra Low Carbon Steels, APIs, HSLA, Dual Phase, Complex Phase and an increasing amount of Advanced High Strength Steels (*AHSS*). Thicknesses vary from 1,2 to 19,0 mm and widths from 700 up to 1880 mm, with a maxim weight of 40t.

AMT Hot Strip Mill has gradually expanded its coil production based on utilization rate and productivity increase. On productivity side, the increase was based on investments, mainly second Reheating Furnace, and continuous improvement actions, mainly related to debottlenecking studies.

In addition to allowing increased production, increased productivity also allows for improved lead times, reduced costs, and other competitive advantages[1,2,3].

To increase HSM Productivity, this project had two main approaches: coil weight increase and process time reduction. To increase the coil weight was necessary to study and review limits of HSM equipment, transportation and customers. To decrease production time, the way was to study and identify production bottlenecks.

According to theory of constraints[4], a process is constrained by the slowest step, and then improvements must address this constraint. Therefore, to improve the performance of a system, it’s necessary to know the main constraint. Once the constraint is identified, the next step is to focus on how to get more production within the existing capacity limitations. Once one constraint is solved, the next slowest process step becomes the new constraint. In a continuous improvement process, we must identify the main constraint each time.

As a complex process, a Hot Strip Mill has different bottlenecks depending on each product, as a combination of steel grade and application, coil thickness and width. For this reason, it was developed a productivity simulator to determine the bottlenecks in each case and actuate in order to increase productivity on each of the main process steps: furnaces, roughing mill, finishing mill and downcoilers.

2 MATERIAL AND METHODS

As mentioned before, an improvement in Hot Strip Mill productivity should consider both parameters used in its calculation, ie the weight of the coil to be produced and the process time required to do it.

$$\boldsymbol{Productivity} = \frac{\boldsymbol{Coil\,Weight}}{\boldsymbol{Production\,Time}} \quad (\mathbf{1})$$

2.1 Coil Weight Increase

To increase coil weight, an integrated project was carried out in cooperation with commercial and planning teams to increase furnace coverage, PIW (pounds per inch of width) and slab width, respecting equipment mechanical and electrical limits.

In a first step, the computational procedure used for Slab Design calculation, in fact a mathematical optimization model, was evaluated and some opportunities for improvement were found by changing the constraints of the optimization process, placing more flexibility of Slab Design rules to always aim slabs at maximum length, stressing the coverage allowed by furnaces, seeking to be as close to the customer maximum coil weight.

After that, studies of the limitations to the length of Transfer Bar and maximum diameter of the Hot Rolled Coil indicated opportunities to increase PIW.

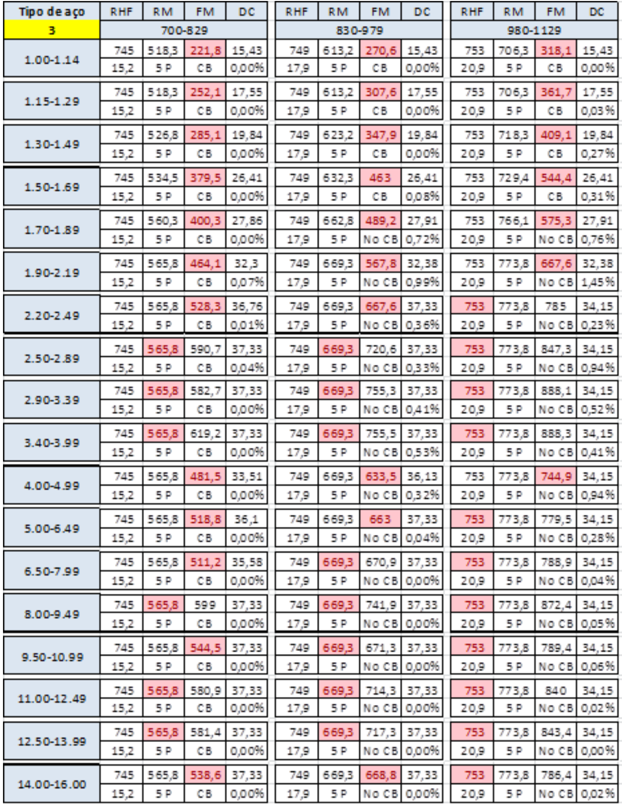
On the other hand, in some cases, width reduction was increased to allow higher slab weight to 225 mm slab by re-evaluation of maximum reductions in Roughing Mill to have an increase in slab width and consequently in slab weight (figure 2).

	Slab to Coil Width Reduction				
Slab Thickness	0	25	50	75	100
225mm	0	0,51	1,02	1,52	2,03
250mm	Limited by maximum PIW				

Figure 2. Weigth gain per Coil with higher slab reduction.

2.2 Production Time Reduction

It was developed a model to calculate productivity for each product, as a combination of steel type, coil thickness and width, on each of the main process steps, ie Reheating Furnaces, Roughing Mill, Finishing Mill and Downcoilers, as shown in figure 2.



Tipo de aço	RHF	RM	FM	DC	RHF	RM	FM	DC	RHF	RM	FM	DC
3	700-829				830-979				980-1129			
1.00-1.14	745	518,3	221,8	15,43	749	613,2	270,6	15,43	753	706,3	318,1	15,43
	15,2	5 P	CB	0,00%	17,9	5 P	CB	0,00%	20,9	5 P	CB	0,00%
1.15-1.29	745	518,3	252,1	17,55	749	613,2	307,6	17,55	753	706,3	361,7	17,55
	15,2	5 P	CB	0,00%	17,9	5 P	CB	0,00%	20,9	5 P	CB	0,03%
1.30-1.49	745	526,8	285,1	19,84	749	623,2	347,9	19,84	753	718,3	409,1	19,84
	15,2	5 P	CB	0,00%	17,9	5 P	CB	0,00%	20,9	5 P	CB	0,27%
1.50-1.69	745	534,5	379,5	26,41	749	632,3	463	26,41	753	729,4	544,4	26,41
	15,2	5 P	CB	0,00%	17,9	5 P	CB	0,08%	20,9	5 P	CB	0,31%
1.70-1.89	745	560,3	400,3	27,86	749	662,8	489,2	27,91	753	766,1	575,3	27,91
	15,2	5 P	CB	0,00%	17,9	5 P	No CB	0,72%	20,9	5 P	No CB	0,76%
1.90-2.19	745	565,8	464,1	32,3	749	669,3	567,8	32,38	753	773,8	667,6	32,38
	15,2	5 P	CB	0,07%	17,9	5 P	No CB	0,99%	20,9	5 P	No CB	1,45%
2.20-2.49	745	565,8	528,3	36,76	749	669,3	667,6	37,33	753	773,8	785	34,15
	15,2	5 P	CB	0,01%	17,9	5 P	No CB	0,36%	20,9	5 P	No CB	0,23%
2.50-2.89	745	565,8	590,7	37,33	749	669,3	720,6	37,33	753	773,8	847,3	34,15
	15,2	5 P	CB	0,04%	17,9	5 P	No CB	0,33%	20,9	5 P	No CB	0,94%
2.90-3.39	745	565,8	582,7	37,33	749	669,3	755,3	37,33	753	773,8	888,1	34,15
	15,2	5 P	CB	0,00%	17,9	5 P	No CB	0,41%	20,9	5 P	No CB	0,52%
3.40-3.99	745	565,8	619,2	37,33	749	669,3	755,5	37,33	753	773,8	888,3	34,15
	15,2	5 P	CB	0,00%	17,9	5 P	No CB	0,53%	20,9	5 P	No CB	0,41%
4.00-4.99	745	565,8	481,5	33,51	749	669,3	633,5	36,13	753	773,8	744,9	34,15
	15,2	5 P	CB	0,00%	17,9	5 P	No CB	0,32%	20,9	5 P	No CB	0,94%
5.00-6.49	745	565,8	518,8	36,1	749	669,3	663	37,33	753	773,8	779,5	34,15
	15,2	5 P	CB	0,00%	17,9	5 P	No CB	0,04%	20,9	5 P	No CB	0,28%
6.50-7.99	745	565,8	511,2	35,58	749	669,3	670,9	37,33	753	773,8	788,9	34,15
	15,2	5 P	CB	0,00%	17,9	5 P	No CB	0,00%	20,9	5 P	No CB	0,04%
8.00-9.49	745	565,8	599	37,33	749	669,3	741,9	37,33	753	773,8	872,4	34,15
	15,2	5 P	CB	0,00%	17,9	5 P	No CB	0,00%	20,9	5 P	No CB	0,05%
9.50-10.99	745	565,8	544,5	37,33	749	669,3	671,3	37,33	753	773,8	789,4	34,15
	15,2	5 P	CB	0,00%	17,9	5 P	No CB	0,00%	20,9	5 P	No CB	0,06%
11.00-12.49	745	565,8	580,9	37,33	749	669,3	714,3	37,33	753	773,8	840	34,15
	15,2	5 P	CB	0,00%	17,9	5 P	No CB	0,00%	20,9	5 P	No CB	0,02%
12.50-13.99	745	565,8	581,4	37,33	749	669,3	717,3	37,33	753	773,8	843,4	34,15
	15,2	5 P	CB	0,00%	17,9	5 P	No CB	0,00%	20,9	5 P	No CB	0,00%
14.00-16.00	745	565,8	538,6	37,33	749	669,3	668,8	37,33	753	773,8	786,4	34,15
	15,2	5 P	CB	0,00%	17,9	5 P	No CB	0,00%	20,9	5 P	No CB	0,02%

Figure 3. Bottleneck simulation output.

Result of initial analysis showed a concentration of furnaces as production bottlenecks (72,57% of the mix), followed by Finishing Mill (19,43%), as can be seen in figure 4.

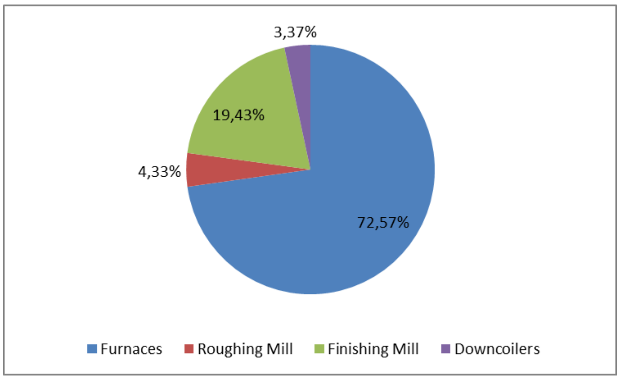
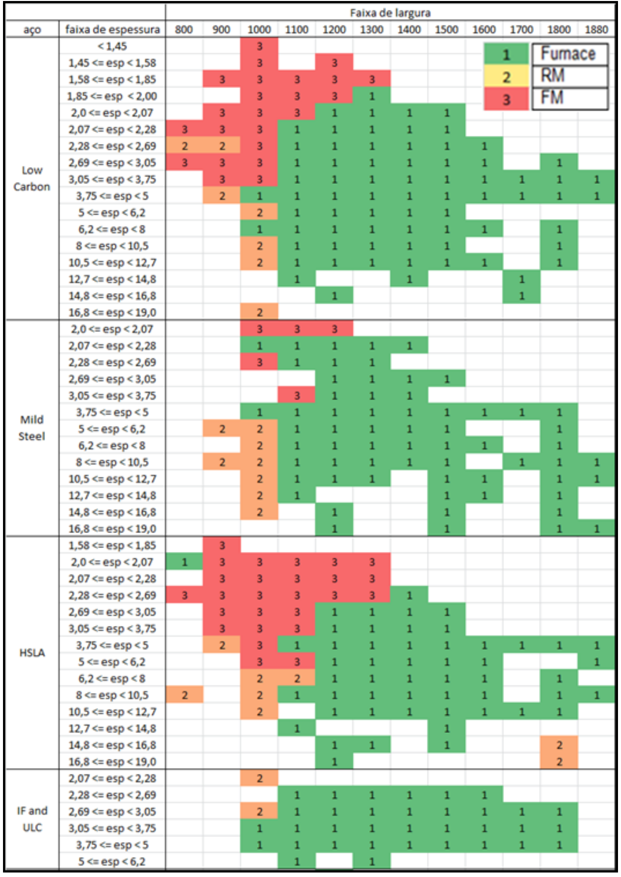


Figure 4. Initial bottleneck configuration.

Based on the results of this model, it was possible to map the bottlenecks for each dimensional combination in all types of steel, allowing a clear visualization of the problem, as shown in figure 5.



aço	faixa de espessura	Faixa de largura											
		800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1880
Low Carbon	< 1,45			3									
	1,45 <= esp < 1,58			3		3							
	1,58 <= esp < 1,85		3	3	3	3	3						
	1,85 <= esp < 2,00			3	3	3	1						
	2,0 <= esp < 2,07		3	3	3	1	1	1	1				
	2,07 <= esp < 2,28	3	3	3	1	1	1	1	1				
	2,28 <= esp < 2,69	2	2	3	1	1	1	1	1	1			
	2,69 <= esp < 3,05	3	3	3	1	1	1	1	1	1		1	
	3,05 <= esp < 3,75		3	3	1	1	1	1	1	1	1	1	1
	3,75 <= esp < 5		2	1	1	1	1	1	1	1	1	1	1
	5 <= esp < 6,2			2	1	1	1	1	1				
	6,2 <= esp < 8			1	1	1	1	1	1	1		1	
	8 <= esp < 10,5			2	1	1	1	1	1			1	
	10,5 <= esp < 12,7			2	1	1	1	1	1	1		1	
	12,7 <= esp < 14,8				1			1			1		
	14,8 <= esp < 16,8					1					1		
	16,8 <= esp < 19,0			2									
Mild Steel	2,0 <= esp < 2,07			3	3	3							
	2,07 <= esp < 2,28			1	1	1	1	1					
	2,28 <= esp < 2,69			3	1	1	1						
	2,69 <= esp < 3,05					1	1	1	1				
	3,05 <= esp < 3,75				3	1	1	1					
	3,75 <= esp < 5			1	1	1	1	1	1	1	1	1	
	5 <= esp < 6,2		2	2	1	1	1	1	1			1	
	6,2 <= esp < 8			2	1	1	1	1	1	1		1	
	8 <= esp < 10,5		2	2	1	1	1	1	1		1	1	1
	10,5 <= esp < 12,7			2	1	1	1		1	1		1	1
	12,7 <= esp < 14,8			2	1				1	1		1	
	14,8 <= esp < 16,8			2		1			1			1	
	16,8 <= esp < 19,0					1			1			1	1
HSLA	1,58 <= esp < 1,85		3										
	2,0 <= esp < 2,07	1	3	3	3	3	3						
	2,07 <= esp < 2,28		3	3	3	3	3						
	2,28 <= esp < 2,69	3	3	3	3	3	3	1					
	2,69 <= esp < 3,05		3	3	3	1	1	1	1				
	3,05 <= esp < 3,75		3	3	3	1	1	1	1				
	3,75 <= esp < 5		2	3	1	1	1	1	1	1	1	1	1
	5 <= esp < 6,2			3	3	1	1	1	1	1			1
	6,2 <= esp < 8			2	2	1	1	1	1	1		1	
	8 <= esp < 10,5	2		2	1	1	1	1	1	1		1	1
	10,5 <= esp < 12,7			2		1	1	1	1	1	1	1	
	12,7 <= esp < 14,8				1				1				
	14,8 <= esp < 16,8					1	1		1			2	
	16,8 <= esp < 19,0					1						2	
IF and ULC	2,07 <= esp < 2,28			2									
	2,28 <= esp < 2,69				1	1	1	1	1	1			
	2,69 <= esp < 3,05			2	1	1	1	1	1	1	1	1	
	3,05 <= esp < 3,75			1	1	1	1	1	1	1	1	1	
	3,75 <= esp < 5			1	1	1	1	1	1	1	1	1	
	5 <= esp < 6,2				1		1						

1	Furnace
2	RM
3	FM

Figure 5. Bottleneck mapping.

Using all these results and information, it was possible to actuate in order to increase productivity in each case.

2.2.1 Furnaces productivity increase

As seen in figures 4 and 5, the bottlenecks in most cases were in Reheating Furnaces. Then main actions initially focused to improve their productivity. To achieve this objective, besides the increase of the furnaces hearth coverage, already mentioned previously, were also performed the following actions:

-Reduction of extraction temperatures (figure 6);
-Adjustment of the gap between slabs;
-Efficiency increase (pipe cleaning, fixing water leakage etc).
-Increase of charging temperatures enabling the Hot and Warm Charge as much as possible (figure 7).

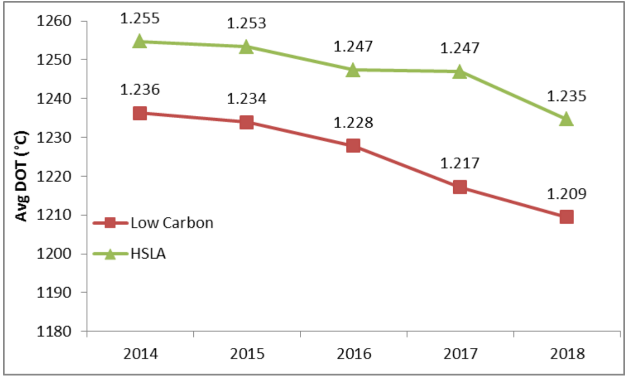


Figure 6. Thin gauge drop out temperature evolution.

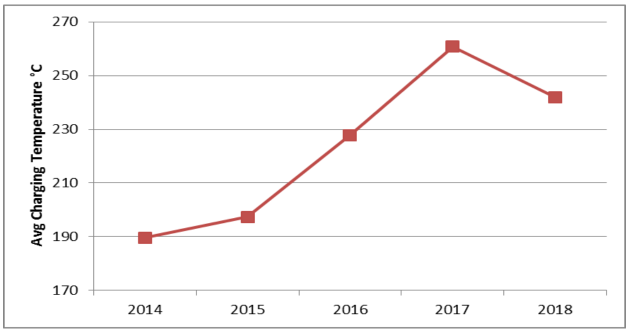


Figure 7. Average charging temperature evolution.

To increase furnaces charging temperatures, main actions were focused on:

-Slab Yard Stock Control (figure 8);
-More flexible sequencing (mill schedule coffin);
-Production planning focused on seek and use at maximum the opportunities to make hot charge (>400°C) or Warm Charge (>200°C);

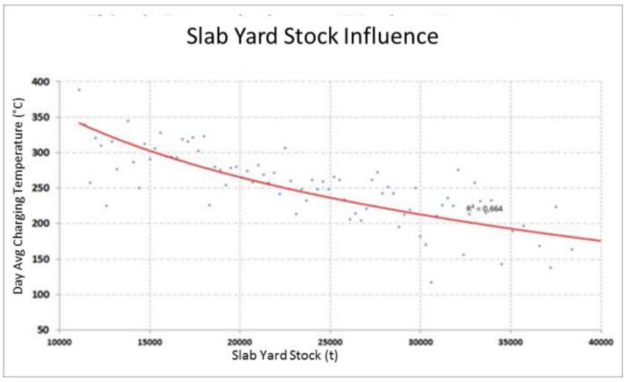


Figure 8. Slab Yard stock influence.

-Slabs Relocation using charging temperature as priority criteria (figure 9);

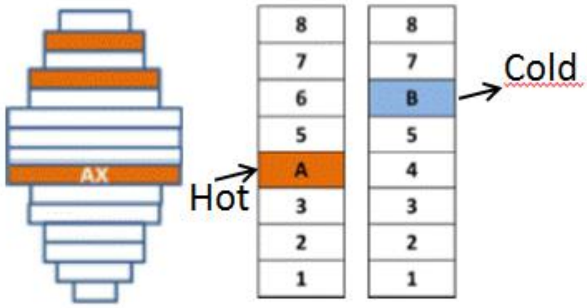


Figure 9. Slab relocation example.

Slab relocation allowed to raise the productivity of ArcelorMittal Tubarão's Hot Strip Mill by changing the HSM's schedule process with optimization of the relocation process of slabs to be charged substituting by hotter ones[5]. The Project began with the revision of metallurgical rules for the relocation of materials, definition of criteria temperature setting (hot, warm and cold definitions), material groupings and change of priorities in the relocation of slabs. With the implementation of the process in the scheduling system, it was achieved an average increase around 5°C in slabs average charging temperature, figure 10.

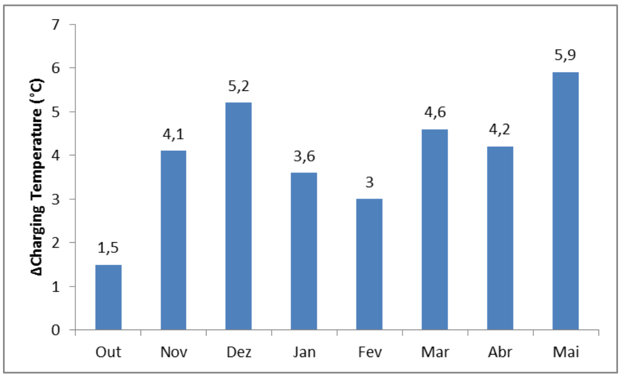


Figure 10. Increase in charging temperature monthly average.

2.2.2 Roughing Mill Productivity

ArcelorMittal Tubarão roughing mill is a reversing type, in which because of its reversing operation, rolling material interference at front and backside can happen, therefore affecting total rolling time in order to avoid material collision. As a result, sometimes this interference also causes a bottleneck.

Then, to increase Roughing Mill productivity, the main actions were related to increase rolling speeds, reversion time and tracking zones optimization to decrease RM cycle time.

The reduction of mill reversion time due to start of reversion before total RM and Edger total gap positioning is exemplified in figure 11,

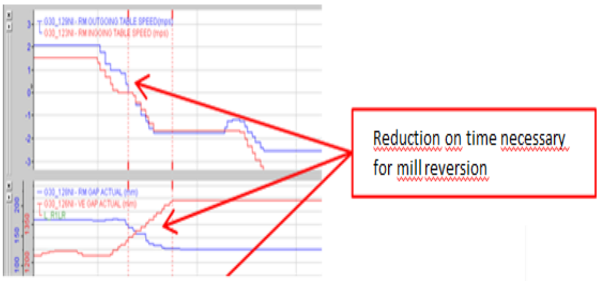


Figure 11. Roughing Mill reversion before total mill gap positioning.

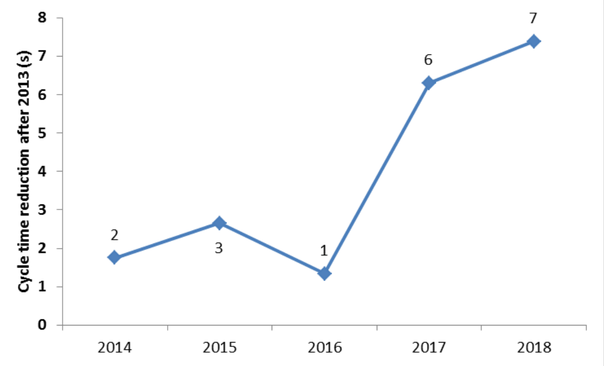


Figure 10. Evolution of average decrease on RM cylcle time.

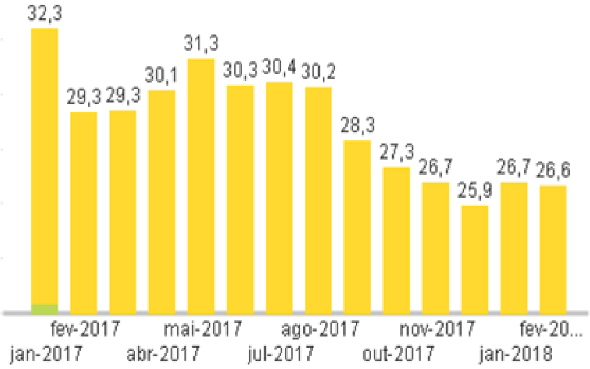


Figure 11. RM InterpassTime Reduction.

2.2.3 Coil Box Bypass

After 2013, with second furnace installation and the new production pacing in order to eliminate time due to CB coiling and uncoiling.

To avoid Coil Box as bottleneck, it was necessary to restrict Coil Box utilization only for thin gages and High Strength Steel Grades. Gradually, coil box use decreased from more than 60% to 15% of total production, as can be seen in figure 12.

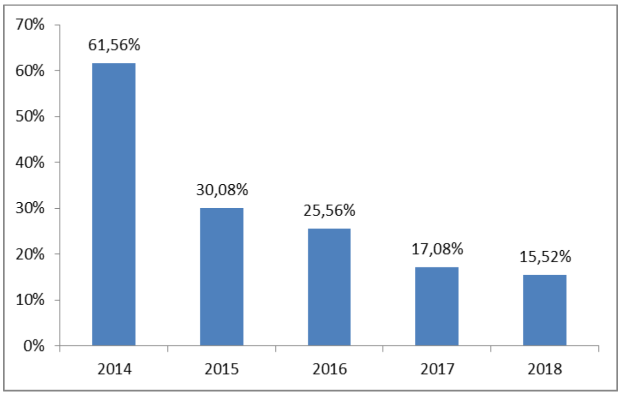


Figure 12. Coil Box usage evolution.

2.2.4 Finishing Mill Productivity

If Finishing Mill train is the bottleneck process, main continuous improvement modifications are related to raise the acceleration ratio and rolling speed.

It's shown in figure 13 the increase in average rolling speeds for HSLA thin gauges (<=2,5 mm).

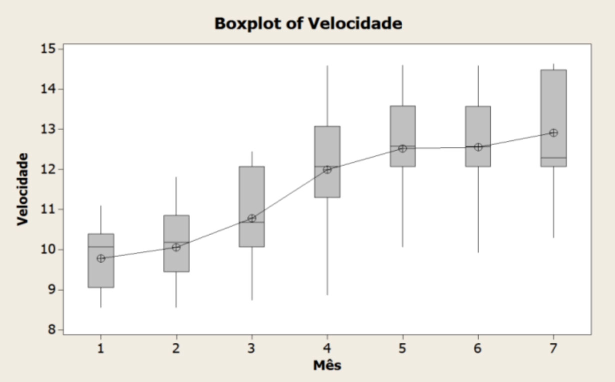


Figure 13. Evolution of thin gauge HSLA rolling speeds.

As a result of rolling speed increase in all steel grades and strip dimensions along last years, it was obtained a significant and consistent reduction in FM total cycle time, figure 14.

On the other side, FM gap time was decreased by optimizing entry mill tracking zones to allow the minimum time between tail end from the previous coil to next coil head end, as exemplified in figure 15.

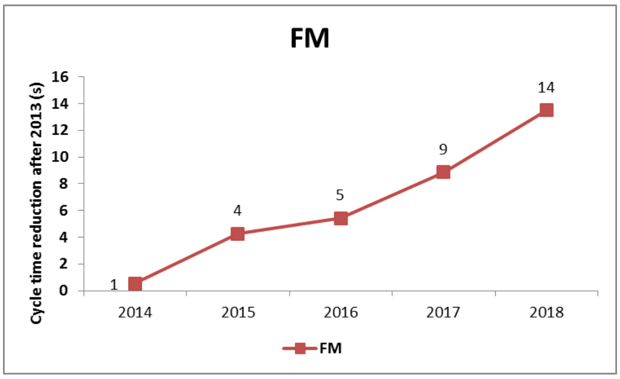


Figure 14. Evolution of average decrease on FM cylcle time.

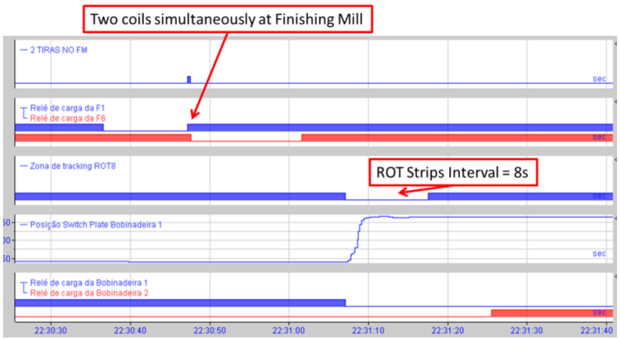
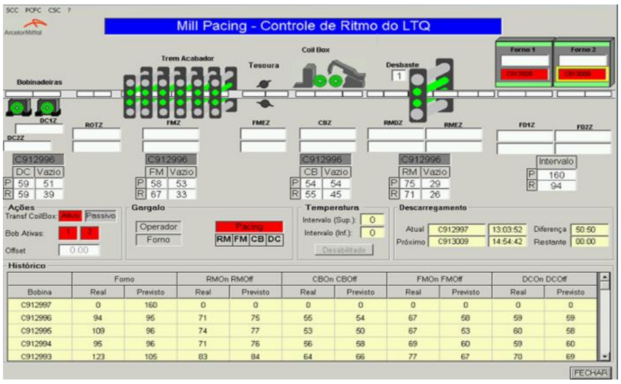


Figure 15. Example of reduction on FM gap time allowing to have two coils simultaneously at FM.

2.2.6 Mill Pacing Control

The purpose of the mill pacing function is to calculate cycles times in each stage of the process and discharge interval to optimize the total time while avoiding material collisions during rolling process.

This function compares each interval cycle time and the interval for furnace heating. The maximum interval is the bottleneck equipment (figure 16). This function stores Fce, RM, CB, FM and DC information that will be displayed at Mill Pacing screen and bottle neck equipment will be indicated to mill operator.



Desbaste: 1

	C912996	
	DC	Vazio
P	59	51
R	59	39

	C912996	
	FM	Vazio
P	58	53
R	67	33

	C912996	
	CB	Vazio
P	54	54
R	55	45

	C912996	
	RM	Vazio
P	75	29
R	71	26

	Intervalo
P	160
R	94

Transf CoilBox: Ativo
Bob Ativas: 1 2
Offset 0.00

Intervalo (Sup.): 0
Intervalo (Inf.): 0

Atual C912997 13:03:52 Diferença 50:50
Próximo C913009 14:54:42 Restante 00:00

Histórico

	Forno		RMOn RMOff		CBOn CBOff		FMOn FMOff		DCOn DCOff	
Bobina	Real	Previsto	Real	Previsto	Real	Previsto	Real	Previsto	Real	Previsto
C912997	0	160	0	0	0	0	0	0	0	0
C912996	94	95	71	75	55	54	67	58	59	59
C912995	109	96	74	77	53	50	67	53	60	58
C912994	95	96	71	76	56	58	69	60	59	60
C912993	123	105	83	84	64	66	77	67	70	69

Figure 16. Mill Pacing screen.

3 RESULTS AND DISCUSSION

As result of the actions described, it was obtained a significant and consolidated increase on resultant productivity of the line, as can be seen in figure 17.

A jump in productivity can be observed from 2013 onwards with the installation of the new reheating furnace, reaching a consolidated level up to 2015, when a new cycle of increase was initiated with the continuous improvement actions described in this work, being increased to new, gradually higher levels until a new level is consolidated from 2017.

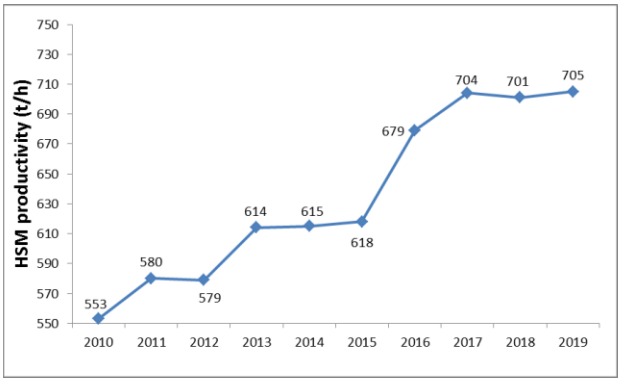


Figure 17. Productivity evolution.

ArcelorMittal Tubarão's production capacity has also increased as a direct effect of increasing productivity, reaching ever higher levels, as shown in figure 18.

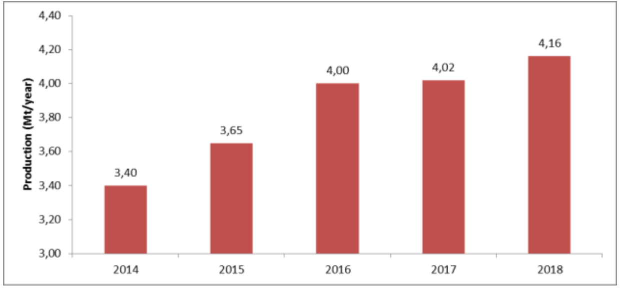


Figure 18. ArcelorMittal Hot Strip Mill annual production evolution.

4 CONCLUSIONS

ArcelorMittal Tubarão's key production productivity simulation model was instrumental in dynamically identifying production bottlenecks, allowing direct actions to increase productivity.

The increase in productivity was then obtained and consolidated through continuous improvement actions that covered the various production stages of hot coils.

As a final result, a significant increase was achieved in the production capacity of the ArcelorMittal Tubarão hot strip mill.

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