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Improved Performance Monitoring and Maintenance Processes using new data systems, sensors, and digital modelling in Cold Mill Roll Shop at Tata Steel Ijmuiden

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The paper presents the research and upgrades in the IT and OT landscape to evaluate and improve the operational performance and maintenance In the Roll Shop of the Cold Mill at Tata Steel IJmuiden. The activities were, as an industrial use case, part of the project entitled "Cyber-Physical System-based approach for intelligent data-driven maintenance operations applied to the rolling area" (Ref. CyberMan4.0 GA 800657), co-funded by the European Union through the Research Fund for Coal and Steel (RFCS).

The Tata Steel use case involved a new data acquisition system in combination with a study to apply Siemens Mindsphere for OEE-monitoring of one grinder (449) based on the World Steel Association standard [1]

The same grinder was also equipped with 14 Shock Pulse Method sensors to monitor the vibration of gear boxes, axis and the hydraulic support to eliminate risks of unplanned stops of the grinder.

The collected data are used as input for a digital model of the roll shop simulating all transport, handling- and grinding steps of work rolls in the roll shop. The model will be used to optimize the overall capacity of the roll shop, based on information obtained from OEE-monitoring and support the new MES-system for planning.

KEYWORDS: STEEL, ROLLING, ROLL SHOP, GRINDER, MAINTENANCE, PDM, OEE, DIGITAL MODEL

INTRODUCTION

Tata Steel IJmuiden's Cold Mill Roll Shop operates in a complex logistic system, as it handles work rolls and back-up rolls from two cold mills, a skin pass mill and four skin pass mills in galvanizing lines. In the summer of 2022, the final step will be made of the revamp of CM21. The roll shop will at certain moments become more and more a bottleneck as schedules will be shorter due to the harder material which is rolled in the mill.

From that perspective, the tools for the operators and staff of the roll shop to monitor the performance, status of the installation and to set up an appropriate planning are quite poor. A long-term program to gradually improve the performance was set up.

IT/OT-LANDSCAPE

The original roll shop IT/OT-landscape consists of isolated systems which are interconnected. The old situation is shown in Fig. 1 and the developed situation in Fig.2.The green stars show the additions and extra

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connections which were made to the landscape. The Roll Shop Management System (RSMS) was delivered in June 2022 and it is foreseen that it will be interconnected with iba and Mindsphere in the near future to unlock more data. Some systems are also outdated, and it is more complicated to unlock the data.

The first target was to enclose the information from the OT-systems. This was done using iba-PDA, which is strong tool to acquire high frequency data. In the roll shop two types of controllers are available. Grinder 449 is controlled by a Beckhoff PLC with an integrated CNC-controller. All relevant data can be acquired from the PLC or can otherwise be constructed within the PLC. The other grinders are controlled by a Siemens PLC and a Numeric Controller and the major part of the data is collected by an ibso datalogger. The acquired data needs to be converted from the hexadecimal ibso format to the iba-format.

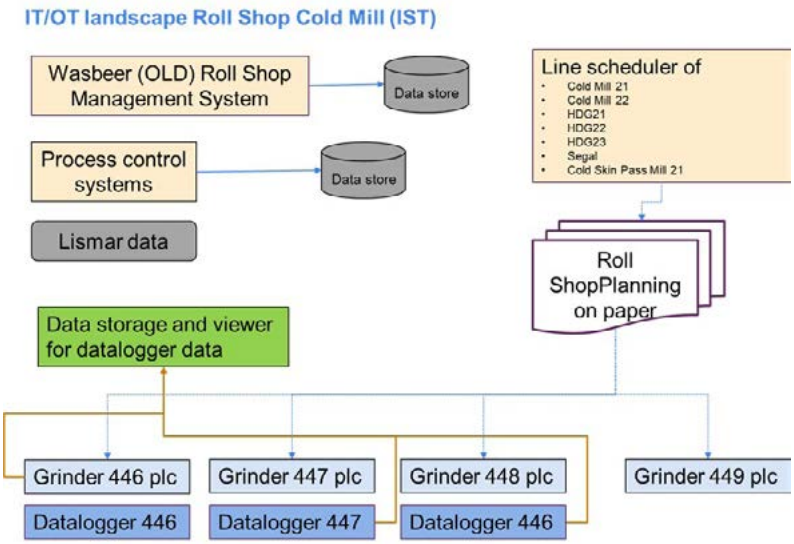

Fig.1 - The IT/OT-landscape of the Cold Mill Roll Shop at the start of the project.

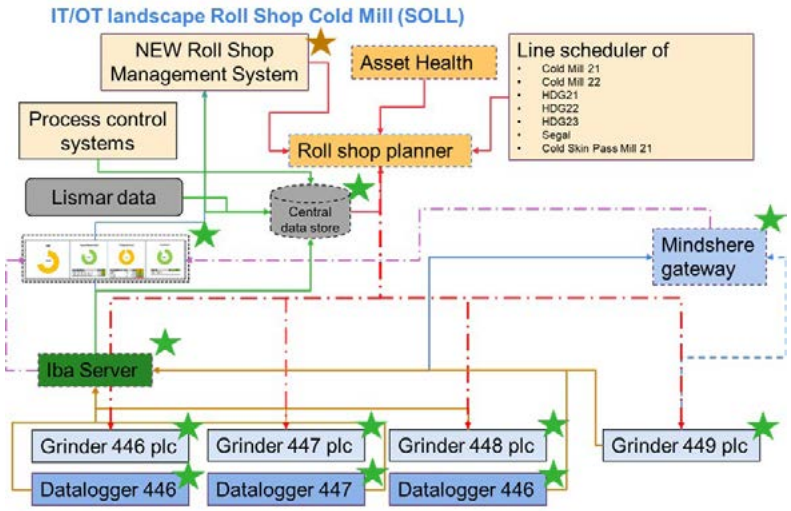

Fig.2 - The developed IT/OT landscape of the Cold Mill Roll Shop per June 2022.

To ingest data in the Siemens Mindsphere platform the data is extracted from iba by an OPC-UA server from there to a Mindconnect box and finally to the Mindsphere platform. Another option is to use an interface which is provided by iba to connect to Mindsphere.

The first option was used to set up a connection for grinder 449 and to develop an OEE dashboard. The principle is shown in Fig. 3.

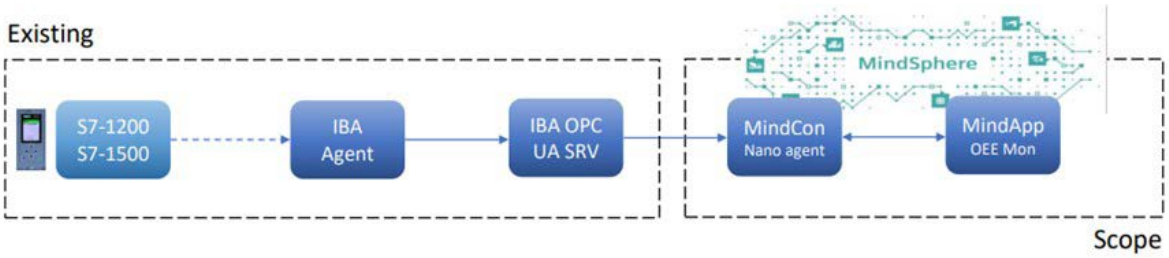

Fig.3 - Connectivity used present OEE-data on the Mindsphere platform.

OEE-DASHBOARD

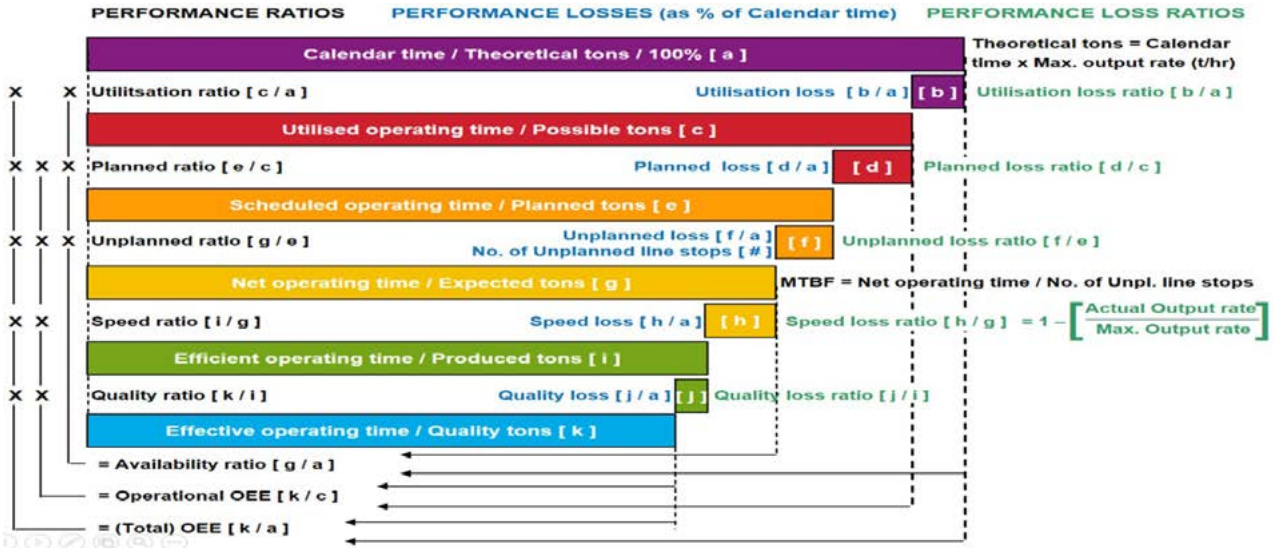

Fig.4 - OEE-breakdown according to World Steel Association.

The OEE-dashboard was based on the World Steel Association standard [1], which is elaborated in Fig. 4.
It breaks down the calendar time in several pieces such as utilisation losses (overcapacity), planned losses (maintenance stops, tool changes), unplanned losses (installation issues, no rolls available), speed losses and quality losses. The last one is the most difficult to assign, the others such as typical grinding time and definitions for unplanned and planned stops can be set in the OEE-app (Fig. 5).

2. **Define error codes and name conventions.**

Time Account	Category of the Time Account		
Productie	**Net Production Time**	Availability Losses	Planned Stops
Laden/lossen	Net Production Time	**Availability Losses**	Planned Stops
Omstellen	Net Production Time	**Availability Losses**	Planned Stops
Wachten	Net Production Time	**Availability Losses**	Planned Stops
Uitgeschakeld	Net Production Time	**Availability Losses**	Planned Stops
Onderhoud algemeen	Net Production Time	Availability Losses	**Planned Stops**
Onderhoud slijpsteen	Net Production Time	Availability Losses	**Planned Stops**

Fig.5 - Example of settings in the OEE-app.

The collected data is stored for a longer time and can be analyzed afterwards. It is possible to improve settings such as the average grinding time per specific roll type and elaborate on the biggest technical issues. The first aspect could only be measured manually by a stopwatch. The attribution of time losses and its cause is now in principle automated: errors can be modified manually as well when needed. All data stored in the Cloud remains Tata Steel's property. Cyber Security aspects has been handled in the design. Roll shop staff has requested to apply OEE on all six machines in the roll shop.

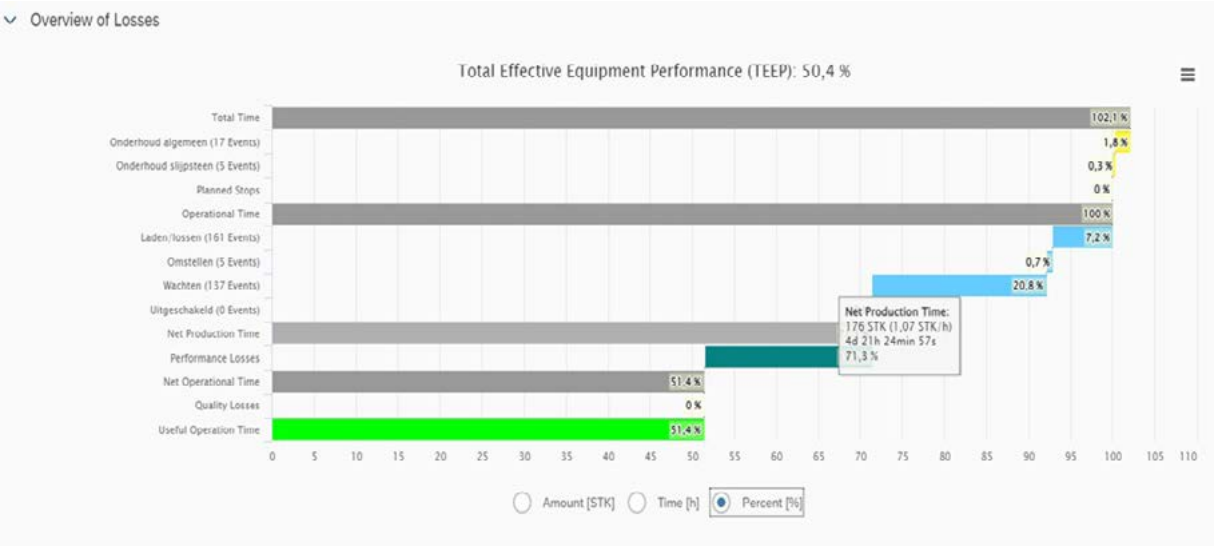

Fig.6 - Overview of OEE during one week in percentage of the calendar time.

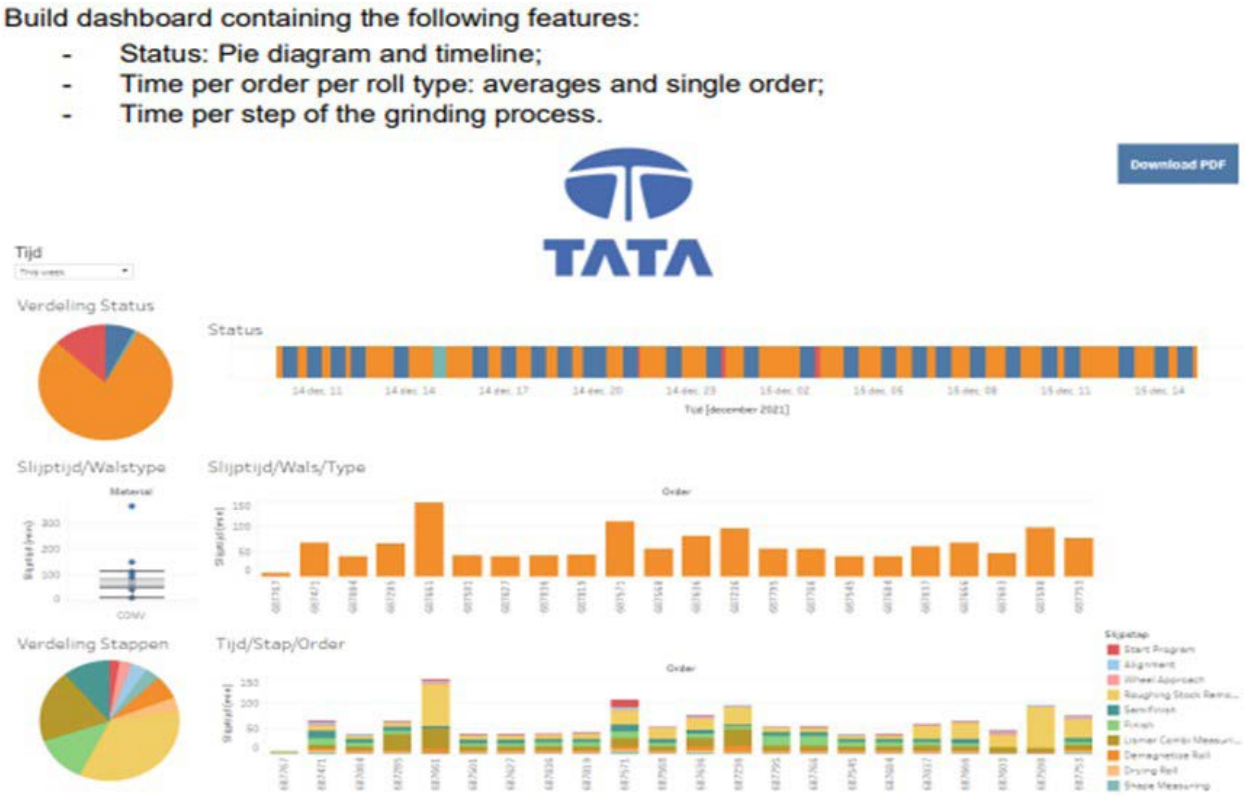

Fig.7 - Analysis of the grinding results based on historical data stored in the Cloud.

CONDITION MONITORING

The same grinder 449 was equipped with Shock Pulse Method [2, 3] sensors, which provide information on the condition of the machine.

Fig.8 - Shock Pulse Measurement sensor mounted on the fixed head of grinder 449.

The combination of Iba PDA, IbA-CMU, Iba-PADU and Iba-CMS will unlock the data from the SPM measurements. At a frequency of 10 – 20 kHz vibration measurements obtained by the Shock Pulse Method and collected by an Iba-CMU unit. The total amount of data is too much to process these continuously. Therefore, snapshots of approximately 1 minute are taken, all at the same process conditions. Signals collected by Iba-PDA, such as rotation speed, are used to select the appropriate process conditions. Iba-Condition Monitoring Systems provides monitoring of bearing systems, to include thresholds and generate alarms at different levels to safeguard the operation. Typical events are shown in Fig. 9:

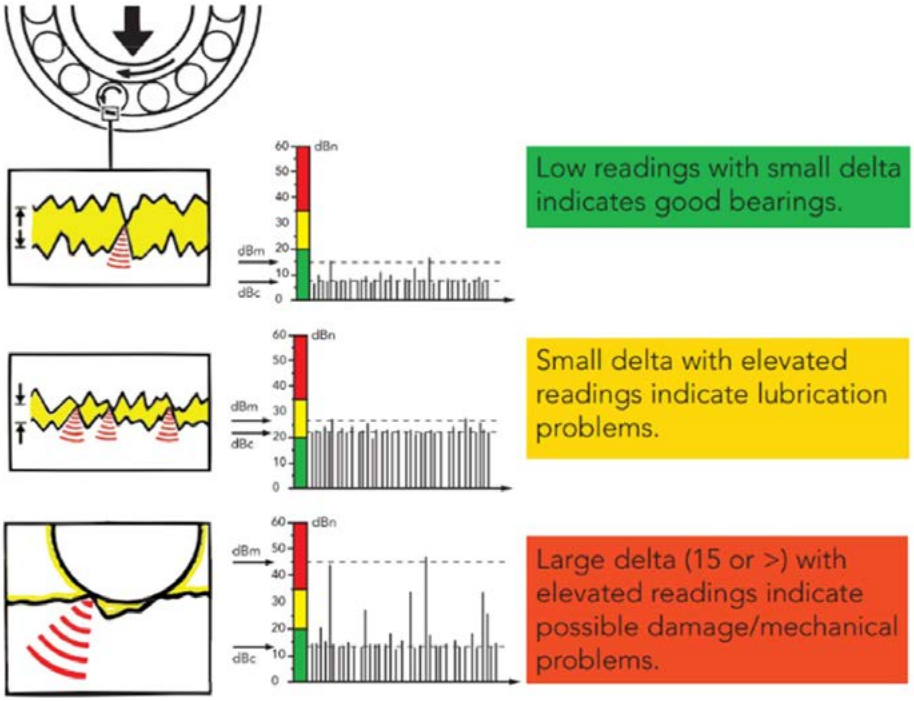

Fig.9 - Shock Pulse Method alarm settings.

- Normal noise level: Green status
- No lubrication on bearing: Elevated readings on the whole spectrum will generate a Red alarm
- Small cracks in the bearing which might be rolled out: A Yellow alarm will be generated. Monitoring on a regular basis is necessary to see how the bearing status will develop. Check alignment.
- Serious cracks in the bearing: Red Alarm. The bearing should be monitored on a frequent basis and preparations for repair should be taken.

The alarm settings provide the possibility to prevent serious installation damage (lubrication, early discovery of misalignment errors after maintenance) as well as to predict the necessary maintenance several months in advance. The status is available daily and replaces manual measurements which are normally ad hoc or at the best periodically executed. The alarms can be coupled to a central Asset Monitoring Digital Center. The introduction of condition monitoring makes it possible to introduce Predictive Maintenance in the Roll Shop.

Based on a FMEA-analysis (See Table 1 and 2), a risk reduction of 35 – 50 % is expected. Normal operation hours will increase, large incidents can be prevented, and work roll quality is more constant.

Tab.1 - Part of the FMEA analysis of a grinder before SPM sensors were placed .

	Occurrence	Effect	Severity	Cause	Detection	Risk	Countermeasure
Failure of the main motor	1	No grinding possible	5	Electrical problems Misalignment	3	15	Check misalignment by vibration measurement
Failure of gear box	1	Work roll shape issues No grinding possible	7	Failing lubrication Misalignment Wear of wheels	7	49	Check lubrication by vibration measurement Check misalignment by vibration measurement

Tab.2 - After SPM sensors were placed the FMEA shows a considerable risk reduction.

	Occurrence	Effect	Severity	Cause	Detection	Old Risk	New Risk	Reduction
Failure of the main motor	1	No grinding possible	5	Electrical problems Misalignment	2	15	10	50%
Failure of gear box	1	Work roll shape issues No grinding possible	7	Failing lubrication Misalignment Wear of wheels	4	49	28	43%

DIGITAL MODEL OF ROLL SHOP

Tata Steel in IJmuiden has set up sharp definitions on Digital Models, -Shadows and -Twins, based on the Digital Twin consortium [4]. The term Digital Twin will only be provided on systems which has direct connections both on the input and output with the real world. A Digital Shadow is only connected on the input side with the real world.

Digital Twins are the most complex of the three and a hard coupled feedback loop to the real world is not trusted by most plant operators. Digital Shadows are sometimes used for testing new functionality. Digital Models could be simulation models: such a model was developed for he Roll Shop.

Since there is no direct input, an appropriate data set must be constructed. This was done by investigating all available roll data from the MES system and check these data whether pinches had occurred and to which severity.

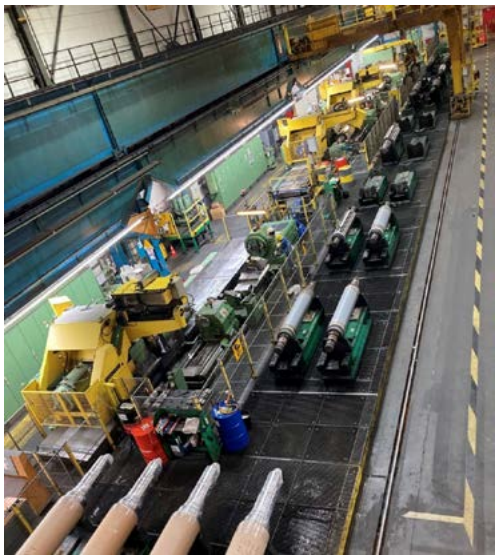

Fig.10 - Roll Shop at Cold Mill.

The model shows the complexity to its full extent. It shows the built-out work rolls from the various mill and even includes transport to them. It also takes in account the time needed to apply an EDT surface texture and/or chrome-plate a part of the rolls at another location at the site IJmuiden. Cranes are essential to transport the rolls from the truck to the position where the chocks are removed and from there to the grinders and backwards. The model is used to discover constraints and to provide insight in the flows in the roll shop. From what looks like a simple treatment, the Cold Mill Roll Shop is a complex logistic puzzle. Various types of work rolls arise from the mill, but they cannot all be ground on the same grinder. There are two essential cranes which at peak moments are overloaded. Apart from the more planned schedules, work rolls with damages from rolling incidents such pinches arise and put extra pressure on the grinder. Sometimes the rolls are taken out of production for several days, as hardened forged steel work rolls contain very high residual stresses, and if damaged in a severe rolling incident (such as a strip break or heavy pinch) they can explode and need to be quarantined and allowed to cool down slowly in an appropriate way. The remaining rolls must be circulated faster.

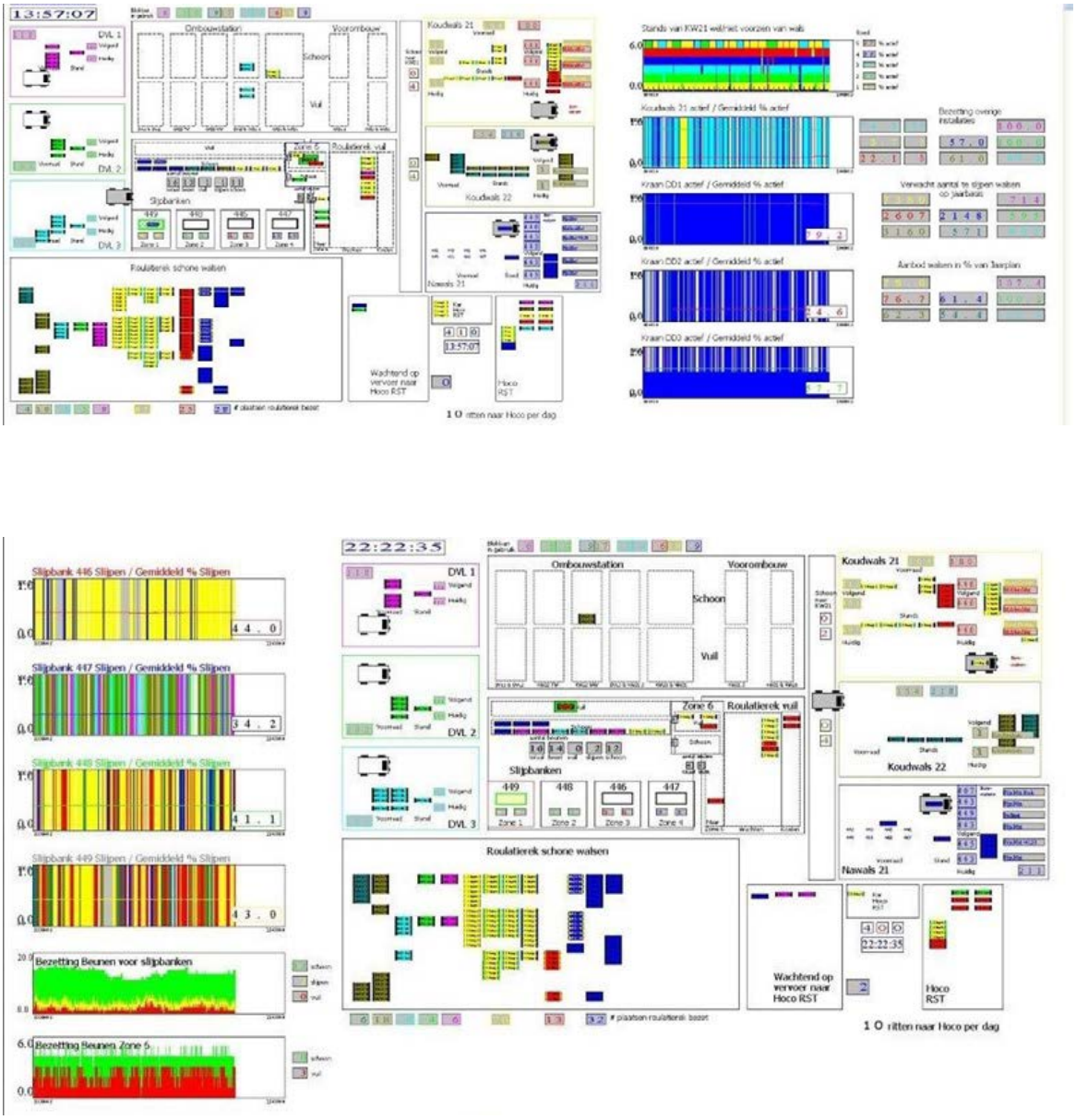

Fig.11 - Two impressions of the Cold Mill Roll Shop Digital model.

The Digital Model is another proof that all equipment in a roll shop, such as cranes and grinders must be in a good shape. It can also be used to test scenarios for maintenance stops, planned grinder revamps and others.
It might that in the future the Digital Model might be transformed in Digital Shadow providing up the up to date Roll Status ate every moment. A last step might be a change to a Digital Twin where the output is used to replan the Roll Shop. With new Cloud and Edge Technology, better data connectors to those platforms, this will come into sight in the coming decade and improved Artificial Intelligence Model this will come into sight in the next decade.

CONCLUSIONS

The IT/OT landscape in the Cold Mill Roll Shop is modernized step by step. The introduction of a new data acquisition systems provides more insight in the operations, for instance to find the root cause of incidents. The date was connected to the IoT-platform Mindsphere, which also contains apps to unlock data. The OEE was set up for one grinder and provides additional insight in its performance and will also be rolled out for other grinders. Additionally one grinder was equipped with vibration measurements to provide insight in its condition. Since the window of prediction is 3 to 9 months Predictive Maintenance can be introduced for the grinder.
The use of a Digital Model was introduced to obtain more insight in the constraints in the Roll Shop.
All these building blocks together fit in the Integrated Maintenance Model 4.0 (IMM4.0) as is described by Colla et. al. [5]

ACKNOWLEDGMENTS

The work described in the present paper was developed within the project entitled " Cyber-Physical System-based approach for intelligent data-driven maintenance operations applied to the rolling area" (CyberMan4.0 GA 800657) co-funded by the European Union through the Research Fund for Coal and Steel, which is gratefully acknowledged. The sole responsibility of the issues treated in the present paper lies with the authors; the Union is not responsible for any use that may be made of the information contained therein.

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Miglioramento del monitoraggio delle prestazioni e dei processi di manutenzione tramite nuovi sistemi di raccolta dati, sensori e modelli digitali nel laminatoio a freddo di Tata Steel IJmuiden

La memoria presenta la ricerca e gli aggiornamenti nel panorama IT e OT per valutare e migliorare le prestazioni operative e la manutenzione nel laminatoio a freddo dello stabilimento Tata Steel di IJmuiden. Le attività sono incluse come caso studio industrial nel Progetto dal titolo "Cyber-Physical System-based approach for intelligent data-driven maintenance operations apply to the rolling area" (Ref. CyberMan4.0 GA 800657), cofinanziato dall'Unione Europea attraverso il Research Fund for Coal and Steel (RFCS).

Il caso studio di Tata Steel ha incluso un nuovo sistema di acquisizione dati in combinazione con uno studio per l'applicazione di Siemens Mindsphere per il monitoraggio della efficacia complessiva di macchina (OEE dall'inglese Overall Equipment Effectiveness) di una rettificatrice (449) sulla base della World Steel Association [1].

La medesima rettificatrice è stata dotata di 14 sensori Shock Pulse Method per monitorare le vibrazioni dei cuscinetti, dell'asse e del supporto idraulico per eliminare i rischi di fermate impreviste della smerigliatrice.

I dati raccolti vengono usati come input per un modello digitale della torneria cilindri che simula tutti gli stadi di trasporto, movimentazione e rettifica dei rulli nella torneria. Il modello verrà utilizzato per ottimizzare la capacità complessiva della torneria cilindri, sulla base delle informazioni ottenute dal monitoraggio OEE e supporterà il nuovo sistema MES per la pianificazione.

PAROLE CHIAVE: ACCIAIO, LAMINAZIONE, TORNERIA CILINDRI, RETTIFICATRICE, MANUTENZIONE, MANUTENZIONE PREDITTIVA, OEE, MODELLO DIGITALE

TORNA ALL'INDICE >