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TECHNOLOGICAL UPGRADES OF SLAB CASTING PLANTS: THE DANIELI DAVY DISTINGTON EXPERIENCE FOR PLANT RENOVATIONS AND PERFORMANCE IMPROVEMENTS[1]

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Abstract
Technological developments in slab casting have introduced numerous significant improvements in mechanical and automation design, and in the associated process technology, enabling recent caster installations to operate with performance levels remarkably better compared to earlier caster installations. Global Players in developing countries had maintained some degree of competitiveness through reduced man power costs, and subsequently benefited from the (then) latest technologies integrated with their newly commissioned plants. As such, the broad base of steel producers now have added incentives to initiate comprehensive cost-effective renovation plans for their casters: Even in times of budget restriction policies, such cost-effective actions not only prolong the technical longevity of their plants but also prepare them with the latest technological developments, maintaining their competitiveness. Danieli Davy Distington's experience includes the world's first production slab caster to its current installations, including the development of the latest casting technologies, coupled with experience in existing plant upgrades, tailoring solutions that range from limited budget applications of technological packages to major caster revamping. There are many incentives for slab casting renovations, incorporating the technological packages developed by Danieli.
Key words*:* Continuous casting; Slabs; INMO.

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1 INTRODUCTION

Since earliest Danieli applications in the late 1950's, continuous casting technology has evolved both in plant design concepts and process features. In particular, productivity and quality gains have now become hampered to a great extent by the mechanical life and design of the original equipment when compared to most-recent designs and applications. Still, slab casters installed just ten years ago are still fully-productive, but in some areas, have fallen behind with respect to latest technological developments. Hence, in order to meet current market product quality demands, such machines often require disproportionately higher production levels to meet quality levels required by their order books, combined with increased unreliability and inefficiencies in comparison to other global competitors.

The past several years have witnessed numerous new State-of-the-Art slab casters installed in developing countries (most notably China). As a consequence, steel producers with older generation equipment, particularly those in industrially-mature plants, industry pioneers actually, are now rapidly finding themselves able to "survive" due largely to the vast experience developed by their operating, technical and maintenance teams. Conversely, as the newcomers gain experience with their equipment investments, the more seasoned steel producers with the aged equipment are likely to become further "equipment-constrained" due to higher maintenance costs and technological limitations. Considering the global nature of the steel business, the flat products sector in particular, product quality and transformation costs are crucial, and will strongly influence relative market competitiveness.

As such, in order to keep pace with global players from developing countries, benefiting largely from reduced man-power costs, and also more recently from the latest technologies, the seasoned steel-producers currently utilizing existing equipment have little choice but to implement comprehensive renovations for their casters. Such renovations, even in times of budget restriction policies, can not only prolong the mechanical life of their plants, but also enable them to become retrofitted with the latest technological developments, and maintain their competitiveness. Experience acquired by Danieli Davy Distington, stemming from the world's first commercial production slab caster in the late 1950, have provided opportunities to fully-develop comprehensive slab casting facility upgrades, with tailor-made solutions, ranging from limited budget technological packages to major caster revamps.

1.1 Incentives for Slab Caster Revamping

A slab caster can be considered obsolete not only because it maintains aged equipment, but also because either it is not possible to attain the increased quality requirements dictated by the market and/or because its products transformation costs are excessive compared to its competitors.

1.2 Quality and Production Considerations

Today's mills (both HSM and plate mills) have dramatically increased their quality requirements demanded by their slab supplies. New processes routes, such as direct hot-charge, eliminate the opportunity for intermediate slab inspection after casting.

Moreover, the production of new high performance grades such as X-100+, Ultra-high strength Micro-alloy, and Multi-phase (Dual-phase, TRIP etc.), demands slabs of consistently superior quality, with improved cleanliness (surface and sub-surface), as well as consistent internal soundness to achieve the superior mechanical properties their intended end-use requires.
In addition to consistent quality production, current markets require casting plants to operate cost-effectively by minimizing maintenance downtime and caster manning requirements. In order to reduce transformation costs, caster designs must provide the technical solutions to ensure extended life to components, many subject to high wear (such as caster rolls), fast exchange capabilities of operational equipment (such as mold and segments), and streamlined equipment maintenance provisions. Such high levels of reliability are even more important when the operating goals include high yield, utilizing sequence lengths of 1,000 ladles and higher. In some cases, wherein casting is maintained for several weeks, producing 330,000 tonnes without sequence interruption, not only is highly reliable equipment required, but also the very latest in process technology, including break-out avoidance provisions, flexible in-line slab width adjustment, advanced equipment diagnostics and predictive quality capabilities. Still, an ever-increasing degree of plant automation is also sought and found to be highly beneficial, optimization efficiency. Examples would include the so-called “operatorless-casting”, which not only reduces transformation costs, but can significantly improve plant safety, and in some cases, slab quality as well.

2 MATERIALS AND METHODS

In order to overcome the challenges faced in current markets, the following solutions have been implemented in recent Danieli Slab Caster installations, which can also be implemented in other facilities as technological upgrade packages for select areas of the casting machine.

2.1 Mold & Oscillation Improvement

Caster molds demand quick-change-capable designs, integrated advanced breakout prevention systems, and in-line cast-width adjustment capability to reap high production levels through accommodating dynamic order (width) schedules, and reduced planned and unplanned downtimes (ex. breakouts).
Hydraulic oscillating systems should be considered instead of electromechanical types, for their advanced guidance systems and flexibility with regard to operation practice solutions. Practices can be quickly and easily-developed, to make real-time adjustments to account for select steel grades sticking or depression-prone tendencies, for instance. Added incentives include practice developments to combat corner cracks, and better-prepare the cast product to avoid hot-scarf routing, facilitating direct-charge should that be preferred. The INMO (*INtegral MOtion*) Mold was developed by Danieli Davy Distington, precisely to achieve uncompromised performance with regard to these aforementioned requirements. It has proven very effective on new slab caster installations, but can also be easily integrated as a stand-alone package, as was recently implemented in the ArcelorMittal Bremen Stahlwerke facility (Germany) as well as at, both, Chengdu Iron & Steel and Sanming Iron & Steel slab casters in China.

Figure 1 shows the INMO mold and oscillation unit utilized at ArcelorMittal Dunkerque's (France) revamped slab casters.

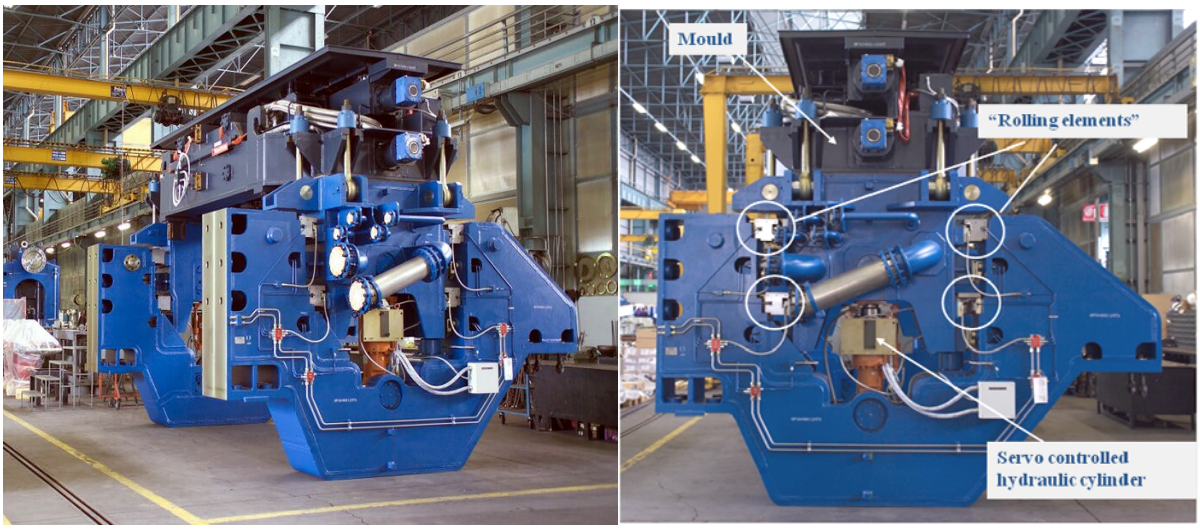

Figure 1. INMO Mold & Oscillator (corner and side views).

2.2 In-Mold Fluid-Dynamics Control

Application of the Danieli Rotelec Multi-Mode Electro-Magnetic Stirring (MM-EMS) technology can achieve any of acceleration, deceleration and rotative functions. The technology is based on the Steel Flow Pattern concept, i.e., the discovery of the way liquid steel moves during its solidification in thick slab caster molds is not of any kind: it can be double-roll, single-roll or permanently unstable. Moreover, steel flow affects steel quality, machine operations and yield; and there is a preferred path!
Danieli Rotelec has incorporated MM-EMS on several casters in Japan, Korea, China, and Belgium with the goal of improving slab and coil quality, preserving operations versatility, maximizing machine productivity, and optimizing slab application ratio. The latest design incorporates the unique capability of performing real-time vertical positioning of the unit according to casting conditions and steel grade attributes to achieve the optimum in-mould steel flow.

2.3 Historical Caster Roll Limitations and Solutions

Service life and reduced-maintenance requirements have become more easily attainable through the use of multi-split roll designs, which have provided not only for optimum slab containment, but also for increased roll loading tolerance, improved internal cooling and enhanced cladding provisions. Since 1986, Danieli Davy Distington has adopted multi-split rolls in slab casting, coupled with tight-pitched roll layouts to ensure sufficient across-slab support and to minimize between-roll bulging, both of which could otherwise seriously compromise internal quality (cracking and segregation).
Internal roll cooling design is very instrumental in minimizing uneven internal roll temperatures and resulting roll internal stresses leading to thermo-mechanical roll wear or failures. These stresses are exacerbated during periodic and prolonged strand speed

slow-downs or, even worse, stoppages. In particular, strand stoppages generate the most extreme conditions for uneven across-roll temperatures. The latest development is the Danieli CoolRoll, which has demonstrated to be very effective, utilizing either a center-bore or peripherally-drilled roll (PDR) configuration, depending on roll diameter. These CoolRolls were developed with maintenance improvements in mind, utilizing modular design solutions to facilitate easy dismantling for maintenance, even after prolonged machine service. Superior multilayer stainless steel cladding has also been developed in order to guarantee the correct surface hardening, ensuring, both, improved slab surface quality and extended roll life. The PDR roll was designed to minimize roll failures in particular for operations experiencing excessive speed slow-downs, and to also provide additional service life between dismantling and inspection procedures. In some cases, over 10 million tons have been cast with these rolls between maintenance procedures even when subjected to long casting sequences of 1,000 ladles or more between re-stranding (Figures 2 and 3).

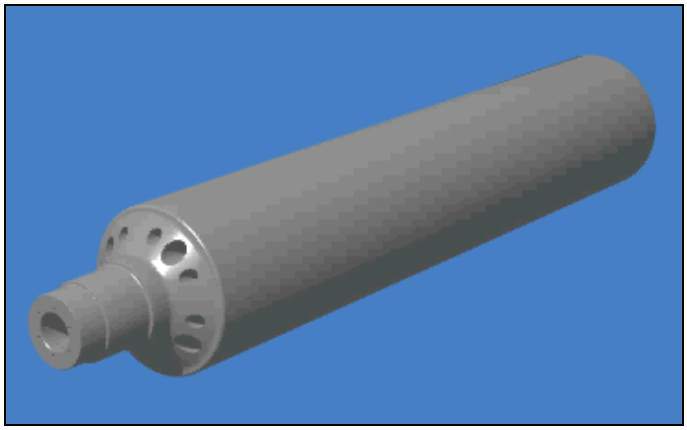

Figure 2. Danieli PDR roll.

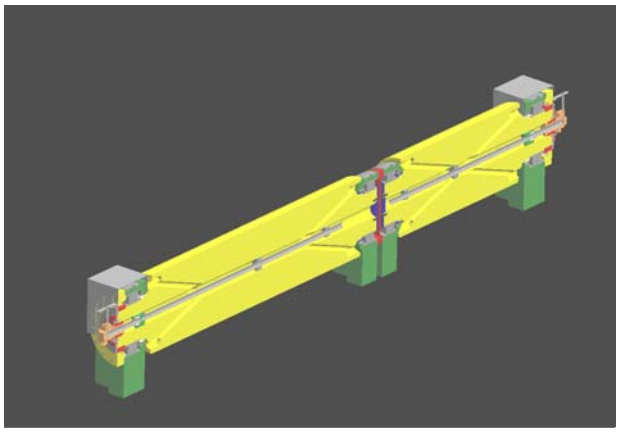

Figure 3. PDR roll internal water flow path.

2.4 Secondary Cooling Constraints Resolution

Dynamic Secondary Spray Cooling has proven to be very effective in positively influencing and maintaining desired metallurgical conditions during strand solidification,

reducing mechanical bending/unbending stresses experienced within and on the slab, and reducing the propensity for several types of cracking, be it reheat-type strains or those generated during periods of low-ductility, for instance. Moreover, Dynamic Secondary Spray Cooling may also influence the final solidification point in the cast strand (allowing an incremental increase in casting speed) and associated shell thickness/strength along the strand, rendering the strand less influential in potential mold level control oscillatory disturbances generated possibly by in-strand Dynamic Bulging phenomena, a roll out-of-pass-line, or a bent roll, to name a few.
The Danieli CoolControl package is dedicated to secondary cooling performance, and utilizes a sophisticated mathematical model incorporating the latest algorithms to continuously compare the thermal history of virtual strand “slices” as predicted by real-time casting conditions, adjusting spray-water to achieve uniform solidification and thermal profiles required by steel grade metallurgy during both steady-state and transient casting conditions. The CoolControl model is applicable to both air-mist and hydraulic media secondary cooling systems. Depending on steel grade requirements and casting conditions, CoolControl can be applied to perform any of “Soft-cooling”, “Hard-cooling”, or “Dry-cooling”, facilitated through the use of recent generations of High-Efficiency spray nozzles, possessing a broad impingement to improve heat-transfer efficiency over a larger volumetric range. Finally, independent width-specific spray-zone control enables the CoolControl application to adapt the spray cooling flow profile according to slab width to avoid potential edge/corner overcooling conditions.

2.5 Resolution for Segment Design Limitations and Soft Reduction Constraints

Segments of suitable design, incorporating structural robustness and low maintenance, are most-suitable to apply Dynamic Soft Reduction process to improve internal slab soundness.

Figure 4. The Danieli Optimum segment

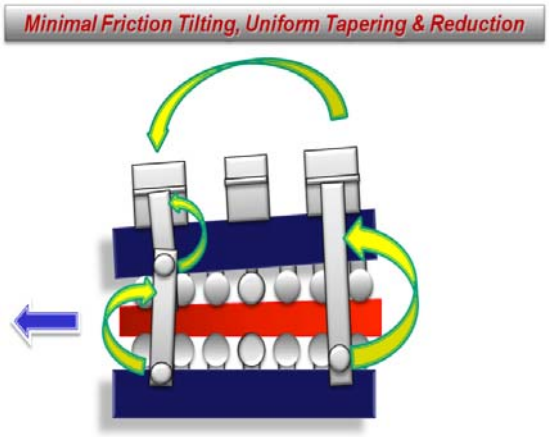

Figure 5. Segment Tilting Condition.

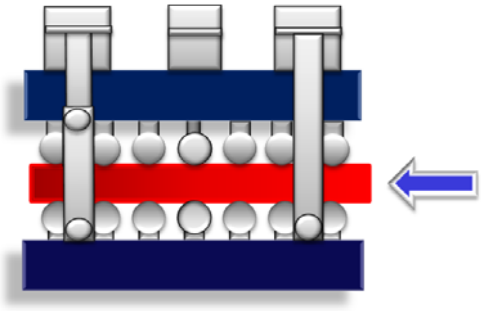

Figure 6. Segment Pre-Tilt Condition.

The earliest industry developments of Dynamic Soft Reduction stem from Danieli's experience during the late 1990s with conventional and thin slab casters. The efficacy and benefits of Dynamic Soft Reduction soon became evident as the system continued to evolve. Through close collaboration with the maintenance teams of Danieli's customers, the Optimum segment (Figures 4, 5 and 6) was subsequently designed in order to apply the required linearly-progressed roll gap reductions, with accurate position control and force distributions along the casting strand, pertaining to real-time casting conditions. A key feature is detailed in Figure 5, which illustrates the unique and patented 3-point pivot/tilt design that provides for minimal friction tilting, uniform tapering and reduction.

Segment structural robustness is particularly important when applying Dynamic Soft Reduction, as increased loading occurs with progressive reductions. Another design provision emphasized by earlier discussions with the aforementioned maintenance teams is easy-access to rolls, couplings, nozzles and on-board (maintenance-specific) instrumentation. The quick-coupling hose designs, for the majority of utilities and electric connections, assist in a shorter segment exchange time. In addition to Dynamic Soft Reduction applications to improve internal soundness, the Optimum segment design can be employed to apply the necessary roll gaps for "thermal-taper", ensuring the segment idler rolls maintain contact with the strand, but can also be utilized to simply accommodate the final slab thickness requirements of subsequent rolling operations (without changing the mold thickness) for improved hot-mill productivity.

3 RESULTS AND DISCUSSION

3.1 Machine Type Conversion – Curved to Vertical-Curved

A Vertical-Curved Slab Caster Design provides significant benefits over the previously more common Curved-Design, particularly wherein optimum internal quality is required, as in Interstitial-Free (IF) grades, which are notoriously-sensitive to “Pencil-pipe” defects, and for which reduced casting speeds would be maintained to avoid such defects. To achieve the required casting speeds and increased productivity, thus strengthening a plant’s competitiveness, and overcome internal defects including inclusion entrapments experienced with several grades, existing plant roller layouts were converted by Danieli Davy Distington to incorporate a Vertical-Curved design, without modifications to existing casting floor levels or to foundations.
The extent of such a conversion may be confined only to the upper portion of the machine or to the entire machine containment, depending on the needs of the customer and the limitations existing with the previous roller bow-section layout, for instance. In the case of AM Sollac Fos Sur Mer Slab Caster Number 2 (France), the Curved-to-Vertical-Curved conversion included a complete revamping to meet a relatively broad grade-mix, and to avoid falling short of the customer’s requirements experienced earlier with a Curved to Vertical-Curved revamp of their No. 1 Caster, which had undergone only a top-end conversion, implemented by a different supplier.

3.2 Machine Type Conversion – Vertical-Curved to Curved

Conversely, where low internal strain tolerances exist, as for very high carbon grades, versus strict cleanliness requirements, solutions have been implemented at Mechel (Russia), and at Carsid (Belgium), where successful Vertical-Curved to Curved conversions were implemented, thus allowing each caster to produce a new and broader product mix, including those grades with relatively low internal strain tolerances, vis-à-vis a larger radius caster and only one region of strand bending (straightening area).

3.3 Manpower Optimization

Efficiency and Safety is becoming increasingly more important in steel plants where manpower reductions are desired, including the Casting area. In particular, for potentially dangerous applications, the following stand-alone package solutions can be considered for safety enhancement through manpower reduction provisions:

- Remote Robotically-Controlled Oxygen-lancing in response to occasional ladle slide-gate opening failures;
- remotely-Controlled Segment Exchange Handling;
- remotely-Controlled, On-line, Dynamic Segment Roll Gap adjustment;
- robotics for mold-powder feeding (Figure 7), as well as SEN Exchange & tundish sampling for steel composition & temperature.

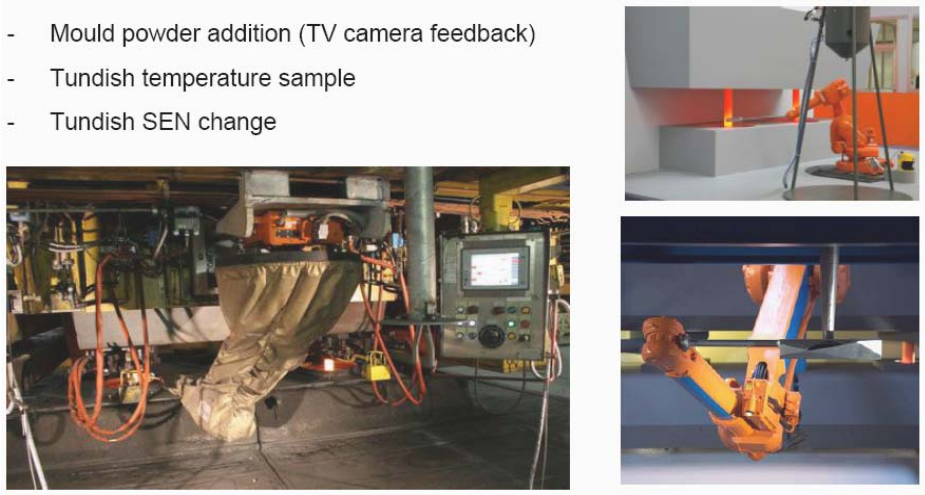

Figure 7. Danieli robotics utilization shown herein for mold powder application. Other applications include tundish temperature sampling and SEN exchange.

3.4 Automation and Diagnostic Packages

Significant plant performance improvements can also be achieved through implementation of standalone software packages, dedicated applications developed by Danieli for the collection, interpretation, process control and reporting from available field data, for product quality prediction and tracking.
These packages include:

3.4.1 Advanced mould-thermal mapping

Through an intelligent arrangement of in-mold thermocouples coupled with a powerful Thermal Mapping algorithm, shell formation and integrity is closely monitored for uniformity and anomalies. This tool provides an advanced breakout warning function coupled with automated speed-adjustment actions depending on the severity of the anomaly and calculated time for the upset condition(s) to heal. In some situations, only a minor casting speed adjustment is required, whereas in other cases more significant casting speed reductions may be necessary. In addition to reactive responses, real-time monitoring is also employed, as for mold powder melting and lubrication performances, as well as in-mold steel shell-to-mold contact condition, highlighting possible shell compromises which may later manifest as bleeds or longitudinal cracks, for instance.

3.4.2 Mould level stability Improvements

Advanced Mold Level Control Systems are popular solutions to improve meniscus stability. Such control systems have been refined to monitor and stabilize mold meniscus levels, utilizing radioactive and electromagnetic-type sensors (according to the specific application). The proven Danieli HiLevel, intelligent mold level control system, is a renowned and proven system to help bring stability to otherwise unstable mold level phenomena, which can contribute to a number of quality issues affecting both surface and internal quality. The HiLevel control package combats many of the phenomena which can lead to level disturbances including Dynamic bulging, flush-through conditions, and standing waves, in addition to the more usual potential mold level upsets resulting from rapid speed changes, and meniscus percolation due to

biased-flow SEN conditions. Correction of poor mold level can have a profound benefit on final product quality, enabling slab casters to resume normally higher production levels, which may be intermittently compromised due to speed reductions in response to occasional level disturbances. Recent applications of mold level control system refinements are now based on even more sophisticated and proven algorithms, such as the Linear Quadratic Gaussian (LQG) system developed by Danieli Automation, shown to be very effective in stabilizing mold level fluctuations. In particular, this patented system has systematically proven to control mold level control fluctuations to less than +/- 1.5 mm, even for ultra high casting speed conditions experienced with Danieli's Flexible Thin-Slab Casters (fTSC) operating with casting speeds greater than 7 meters per minute.

3.4.3 The need for real-time slab quality assessment: Quart (quality assessment in real time)

Advancing upon earlier versions of slab quality rating systems, of which there are many, the Quart system was created to address shortcomings with these earlier systems (Figures 8 and 9).

Assigned slab coding to reflect:

- Internal condition;
- surface condition;
- core condition;
- corner condition;
- overall cleanliness condition;
- ensuring all possible anomalies are recorded for a slab and included in the final quality rating;
- ensuring the most severe anomaly dictates the disposition routing and allowed end-use;
- ensuring the assigned code clearly identifies the quality level and targeted disposition;
- ensuring the assigned code clearly reveals the relative defect severity for all product regions: internal, surface, core and corner etc.

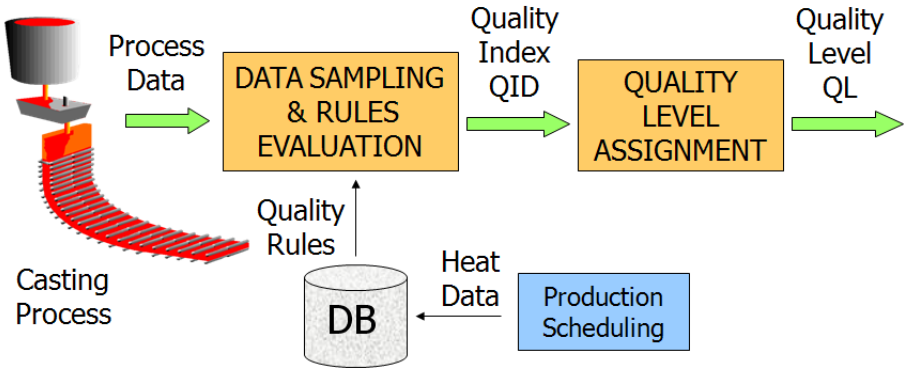

Figure 8. Quart (Quality Assessment in Real Time) overview.

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Equally important, is to ensure such a system provides for flexibility and user-friendliness to create tailor-made flagging and defect assignments for upset conditions specific to each facility. Defect assignments may be simple or complex, requiring several field inputs to trigger them. Moreover, the customer can reap the benefit of such a system that grows with them and doesn't constrain their further development. The proven Quart system satisfies this need. As such, slabs may be more efficiently and accurately processed for any of direct hot-charging or cold-charging, including conditioning processes. Accurate defect severity assignment may now help to avoid otherwise unnecessary inspections, hot/cold scarfing or grinding operations. Conversely, defects that otherwise could have been overlooked, can now be properly identified and, along with the appropriate slab conditioning, ensured to become properly removed rendering the slab suitable for the end-use. The often heard desired objective "A ton applied from a ton produced" is now more easily achieved. An added benefit is the real-time nature of this system, which provides key information to the torch cutter for more precisely cutting around these defects where required, therefore improving yield.

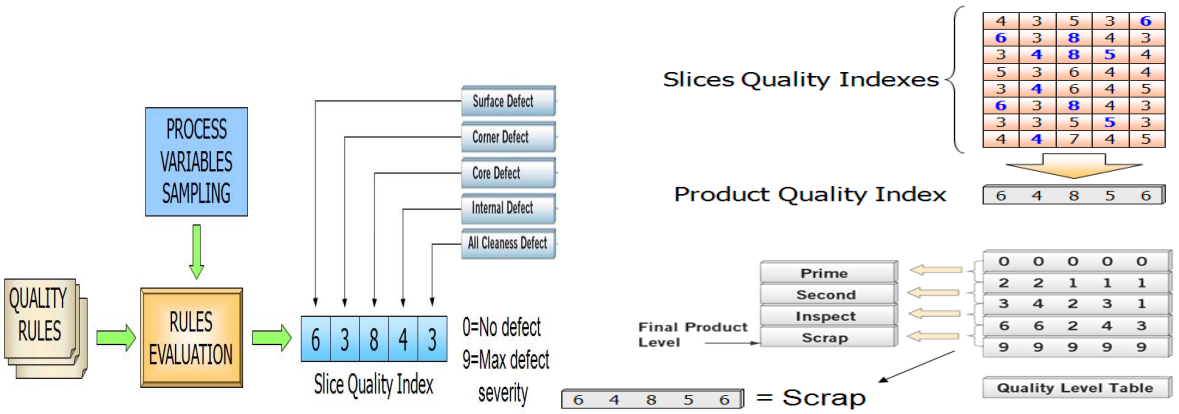

Figure 9. Quart Rating System Criteria.

3.4.4 More intelligence package

A Multi-dimensional Database Analysis system has been recently developed that transforms the vast amounts of production and process data gathered by the various automation systems into tangible, easily-retrieved information to be utilized for subsequent decision-making and overall improved process knowledge. Through the use of advanced Data Warehousing (DWH) and On-Line Analytical Processing (Olap) functionalities, the MoreIntelligence package rapidly and quickly uncovers important information which otherwise would often be hidden within enormous data records, typically generated by alternative automation systems (Figure 10).

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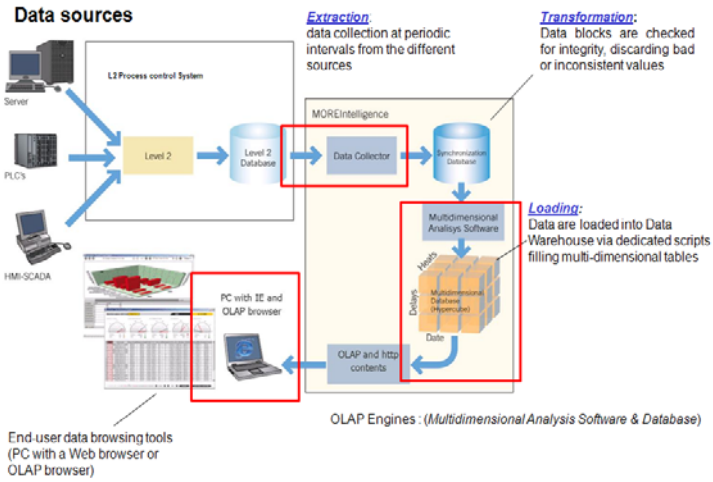

Figure 10. MoreIntelligence system overview.

4 CONCLUSIONS

Current market conditions demand existing facilities to be at least updated with the latest technologies when an entire new plant installation is not an option. In turns out, such partial renovations prove to be very cost-effective, reaping significant financial returns on the initial investment in a very short period of time, as has been demonstrated at numerous facilities. It is clear that common budget restrictions experienced at many steel facilities have crimped planning and spending considerations for upgrades. Still, the inter-connected world steel market and the technological evolution of facilities in relatively lesser developed countries enjoying lower manpower costs have forced numerous facilities in western countries to retrofit their operations with the latest technologies in order to remain competitive. Such limited budget upgrades have occurred not just to replace equipment near the end or past its useful service life, but also to replace equipment unable to keep-pace with maintenance demands or to achieve higher productivity or quality. The Danieli Davy Distington experience in Continuous Casting of Slabs draws upon a wide array of technological innovations implemented initially with newer installations, but now more frequently found in installations requiring area-specific mechanical or automation enhancements, enabling these facilities to keep or exceed pace with other global competitors.