APPLICATION OF TECHNOLOGICAL PACKAGES IN SLAB-CASTER UPGRADES[1]

Andreas Jungbauer [2]
Andreas Flick[3]
Oliver Schulz[4]
Lawrence Gould[5]

Abstract
Following the introduction of technological packages for continuous-casting machines in the early 1990s, VAI, a division of the Siemens Group Industrial Solutions and Services, has successfully upgraded 180 casters worldwide. Major improvements were achieved with respect to productivity, product quality and operational flexibility. Examples of technological packages, project examples and economical results are presented.
Key words: Caster upgrade; Economical results.

1 *Tecnhical contribution to XXXVIII Steelmaking Seminar – International, May 20th to 23rd, 2007, Belo Horizonte, MG, Brazil.*
2 *Product Manager - VAI Continuous-Casting Technology*
3 *Vice President - VAI Continuous-Casting Technology*
4 *Head of Proposals Department - VAI Continuous-Casting Technology*
5 *I&S VAI Press Department, Siemens VAI Metals Technologies GmbH & Co*

INTRODUCTION

The industrial breakthrough of continuous-casting technology took place in the late 1960s and 1970s. Figure 1 shows the number of slab-caster installations since that time from all known suppliers. Older continuous-casting machines, however, are now of outdated design and frequently include curved molds and through-going strand-guide rollers with large diameters, as well as employ straightening of the solidified strand over a single roller. These factors all have a negative impact on caster productivity and product quality. Steel companies are therefore under considerable pressure to upgrade their older casting machines in order to meet the increased demands placed on continuously cast products and to remain competitive.
Beginning in the early 1990s, VAI commenced with the development and implementation of a series of technological packages which enable existing casters to meet today's targets of productivity, product quality and operational flexibility. In the following, a number of such solution packages and application examples are presented. Table 1 provides an overview of the slab-caster upgrading projects received by VAI during the past seven years.

Table 1: VAI Slab-Caster Upgrading Projects (2000–2006)

	No. of Contracts		Market Share
Year	New	Upgrade	Upgrade
2000	2	9	51.2%
2001	6	8	78.7%
2002	8	20	75.3%
2003	11	11	75.8%
2004	11	10	68.3%
2005	10	16	67.7%
2006	8	14	82.7%

Today, approximately 95% of all steel produced on a global basis is continuously cast into semis (slab, blooms, billets, beam blanks). In the early 1990s, a major increase in the number of projects for the upgrading of older slab casters took place, as seen in Figure 1 (all known upgrades). Figure 2 shows the age of slab casters for all known cases at the time that an upgrade took place, which is an average of 18 years.

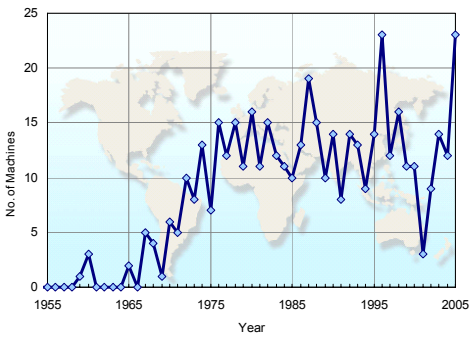

Figure 1: Annual Installation of New Slab Casters (All known suppliers)

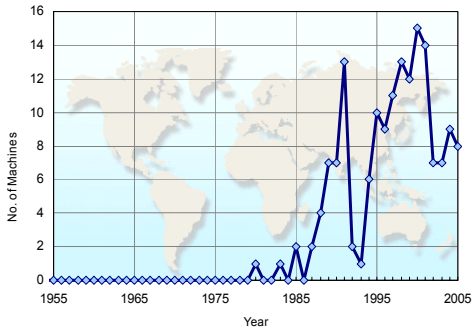

Figure 2: Slab-Caster Upgrades Since the Late 1970s (All known upgrades)

The primary reasons for the upgrading of continuous-casting machines is either to increase machine productivity or product quality or both. Production flexibility is important for producers supplying a market with varying product demands, or where there is the intention to open up new market possibilities. Benefits resulting from caster upgrades also typically include a decrease in operational and maintenance costs.

Product quality can be improved by the conversion of a curved-mold caster design to a straight-mold design. Proper mold oscillation and lubrication is important for the strand surface quality. Increased productivity results from the installation of well designed equipment components and advanced automation systems to reduce machine downtime and to allow for higher casting speeds. This is accompanied by an extension of the machine containment length to accommodate a longer metallurgical length. The application of an advanced cooling model is a decisive factor for assuring high product quality and long component lifetimes even during transient casting conditions. High casting flexibility is made possible with equipment solutions enabling fast strand width and thickness changes.

Typical upgrading measures include the application or installation of the following:

- Conversion of a curved-mold caster design to a straight-mold design to improve product quality, especially at higher casting speeds
- Cassette-type molds to reduce turn-around time
- Hydraulic oscillators to improve strand surface quality and machine reliability
- Dynamic mold-width adjustment to enable high production flexibility
- Segmented strand guides for short maintenance downtimes
- Dynamic soft-reduction technology for high product quality
- New hydraulic systems for improved operational reliability
- Modular and state-of-the-art Level 1 process control
- Level 2 process models to improve product quality and productivity.

TECHNOLOGICAL PACKAGES

Already in the early nineties VAI recognized the market potential for caster upgrading projects and altered a number of fundamental principles in their machine design. For example, instead of a fully integrated design approach, a more modular system design was applied characterized by the use and installation of technological packages at different sections of the caster. This approach proved to be suitable both for caster upgrades and completely new machines. A short description of examples of technological packages is presented.

SmartMold

This solution is characterized by a low-weight yet rigid, cassette-type mold design with a reduced number of operational exchange parts (Figure 3). Both the mold and worn copper plates can be quickly exchanged, increasing the unit's overall availability. When integrated with DynaWidth hydraulic mold-width adjustment system, fast and automatic slab-width changes are possible. 93 SmartMolds have been sold as of January 2007.

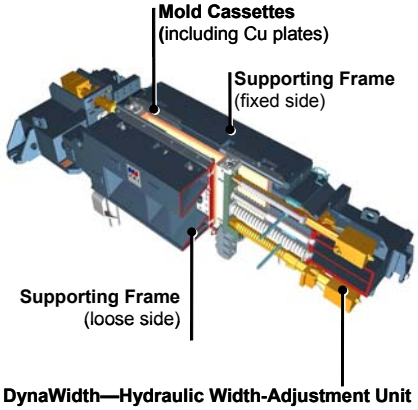

Figure 3: SmartMold—High-Performance Cassette-Type Mold

DynaFlex

The DynaFlex hydraulic oscillator is a technological package consisting of a foundation frame and two individually exchangeable and interchangeable oscillator units, each mounted on a separate leaf-spring-guided mold table and equipped with a hydraulic cylinder (Figure 4). In addition to a freely selectable stroke, frequency and curve pattern, a so-called inverse oscillation mode was also developed to reduce the depth of oscillation marks for an improved strand-surface quality. The system is virtually maintenance-free and is suitable for molds of all types. 97 units have been sold as of January 2007.

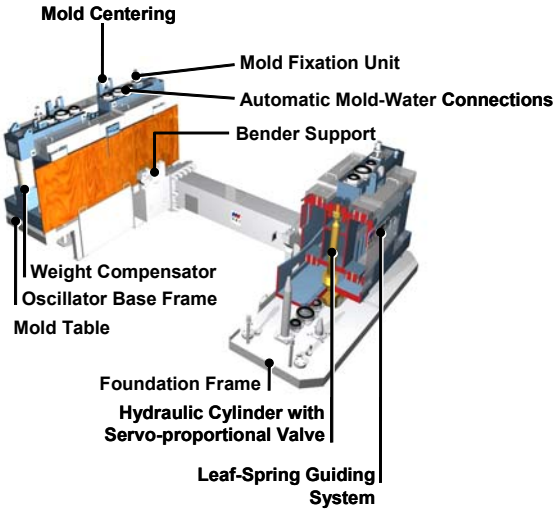

Figure 4: DynaFlex Hydraulic Oscillator

SmartBender

The SmartBender is a fully remotely adjustable first caster segment which allows quick strand-thickness changes to be carried out. This is a major operational benefit for producers requiring frequent slab-thickness changes and caster productivity is kept at a high level. Designed as a self-standing low-weight unit, the unit is equipped with automatic water couplings (Figure 5).

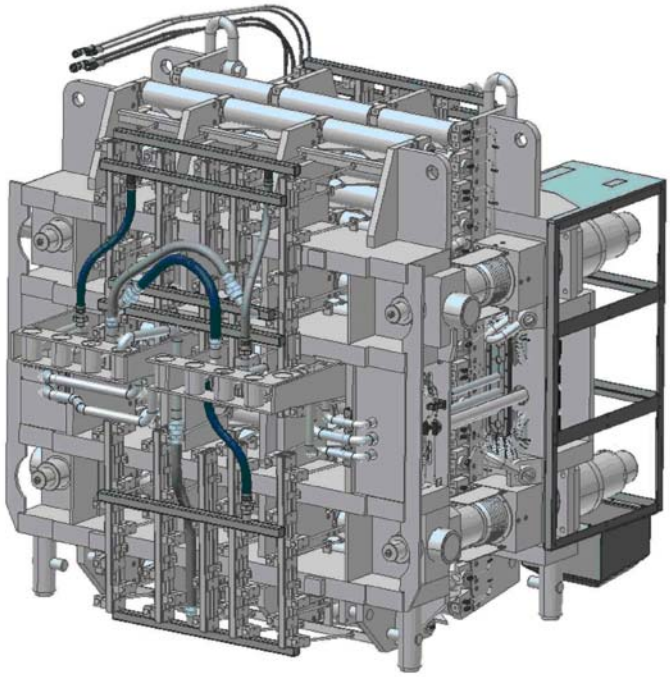

Figure 5: SmartBender Design Features

SmartSegment®

Together with the SmartBender technological package, the rigidly designed SmartSegment enables fast slab-width changes to be carried out through the remote and online adjustment of the roller gap of the strand-guide system. When linked with the Dynacs® cooling model (for calculating the final point of strand solidification) and the DynaGap model (for calculating the roller-gap set points), the optimum roller gap and strand taper can be dynamically adjusted even during transient casting conditions to enable soft reduction and the resulting improvements in internal strand quality, especially for pipe and plate grades (Figure 6). As of late January 2007, more than 69 casters equipped with this technology were sold worldwide since 1997.

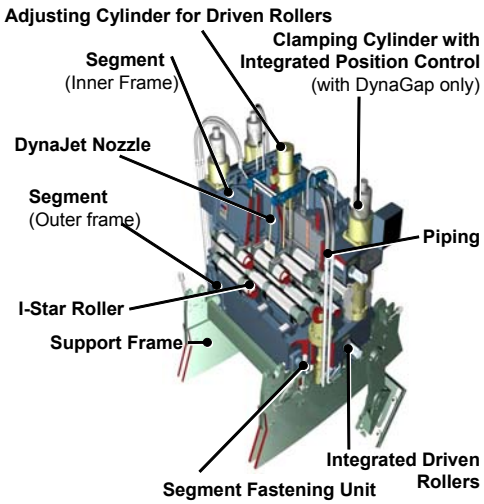

Figure 6: SmartSegment Design Features

Connect & Cast® Solutions

The engineering of Connect & Cast technological packages (e.g., DynaWidth oscillator, LevCon mold-level control, DynaWidth mold-width adjustment, secondary cooling systems and DynaGap) already begins with the commencement of a caster upgrading project. In a parametric approach customer requirements are taken into consideration during the detail engineering of the mechanical, fluid and automation components and systems. Workshop testing ensure the proper functionality and reliability of the total system. These measures contribute to the shortest possible start-up and ramp-up times necessary for minimum production outages.
The impressive and measurable results that can be achieved through the application of "connect & cast" technological packages is shown by a so-called "economical calculation model" in a later section of this paper.

EXAMPLES OF SLAB-CASTER UPGRADES

AK Steel Middletown, U.S.A.

In 1994 AK Steel Middletown awarded VAI an order for the upgrading of their 2-strand slab-caster which was originally commissioned in 1972. The main target of this upgrade was to improve the product quality through the elimination of slab centerline segregation. Highly rigid segments were installed in both casters in addition to the Dynacs spray-water-cooling model. During the installation phase one strand had to be kept fully operational during the main caster downtime period because of production-supply obligations. To minimize onsite construction time, pre-assembly of the entire caster and extensive integration tests were carried out in Linz, Austria prior to shipment. As a customer requirement, the interchangeability of the segments for each caster was already demonstrated during these pre-assembly activities.
Following completion of the upgrading activities and resumption of normal casting operations, the internal slab quality considerably improved, as seen in Figure 7. This can be attributed to the highly rigid segment design, the employment of split rollers for improved strand support—which avoids roll bulging and the related negative

affect on slab quality—and particularly, to the tapered roller-gap settings in the segments for an improved centerline quality. As an additional benefit, AK Steel Middletown could then cast at higher speeds for an increased slab output without the danger of halfway cracks occurring. The Dynacs cooling model significantly reduced the frequency of surface-crack formation, even during abnormal casting condition, which further contributed to an improvement in the quality of the rolled products.

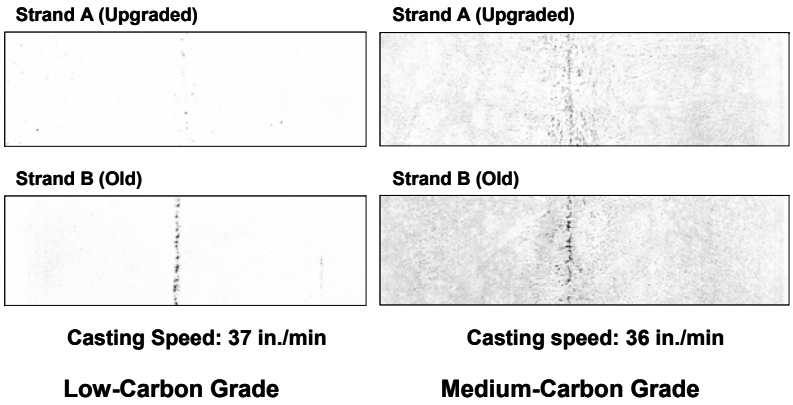

Figure 7: AK Steel Middletown, U.S.A.—Sulfur Print Showing Internal Strand-Quality Improvements

LTV Steel (now Mittal Steel USA)

In October 1998 LTV Steel (now Mittal Steel USA) commissioned VAI to upgrade their No. 2 Continuous Caster at their Indiana Harbor Works (**Figure 8**). The project objective was to completely eliminate "pencil pipe defects" appearing on the cold-rolled, galvanealed sheet products, which could be traced back to the curved-mold design of the existing caster. A further requirement was that the slab-caster output had to be increased by approximately 25%.

Figure 8: Upgraded Caster at Mittal Steel USA, Indiana Works, U.S.A.

The curved-mold caster design was replaced by a straight-mold design in elaborate structural modifications of the caster. To optimize the vertical length of the mold, its fixed side was shifted by 580 mm and elevated in the vertical direction by 310 mm. By bending the strand to a transition radius of 7.5 m and straightening it back to the original machine radius within segment 2, a vertical length of 2,500 mm could be achieved. This "straight mold conversion concept"—jointly developed by Arcelor Sollac and VAI—is now patented worldwide.
The upgraded caster could be restarted on April 30, 2000 after only six days and two shifts for the required machine shutdown. Nominal production could be resumed within three days following caster start-up. The previous quality problems were solved and the caster also satisfied the demand for a higher slab output.

POSCO Gwangyang, Korea

An order was received from POSCO Gwangyang, Korea in 2001 for the upgrading of their 2-strand slab caster CCM1-3. The caster was subsequently equipped a DynaFlex oscillator, the LevCon mold-level control system, DynaWidth mold-width adjustment and DynaGap soft reduction to increase the production flexibility and product quality.
As shown by the start-up curve (Figure 9) only 11 days were required for the caster to reach full production output. This was only possible through the application of “Connect & Cast” equipment solutions with fully operational technological packages right from the first heat.

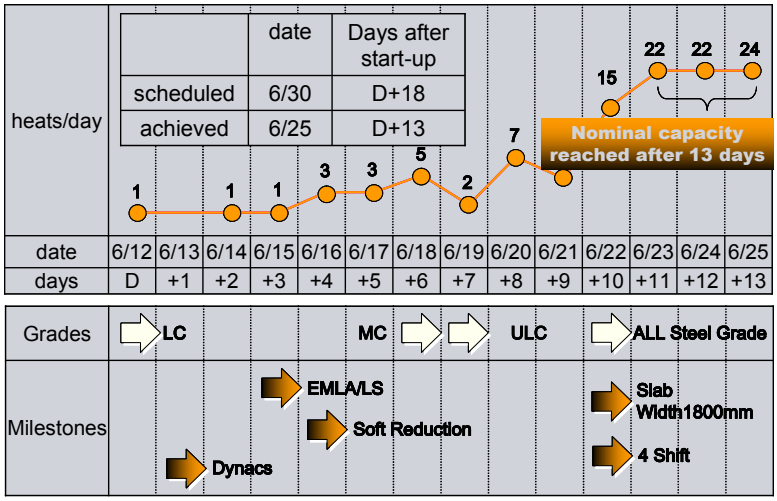

Figure 9: Slab Caster Start-up Performance at POSCO Gwangyang, Korea After Upgrading

Since the completion of this project VAI has received additional orders from POSCO for the upgrading of a second 2-strand slab caster at Gwangyang, two 2-strand slab casters at Pohang in addition to one single-strand stainless-steel-slab caster also at the Pohang works.

UGINE & ALZ Genk, Belgium

In an upgrading project implemented by VAI at the world's largest stainless-steel slab caster, the caster output had to be doubled to 1.2 million tons per annum. The project scope included the conversion of the curved-mold design to a straight-mold design, modification of the machine to allow for both single- and twin-slab casting, an increase of the maximum possible slab-casting width to 2,330 mm, extension of the vertical casting length for product-quality reasons, and the extension of the caster length to allow for a faster casting speed.

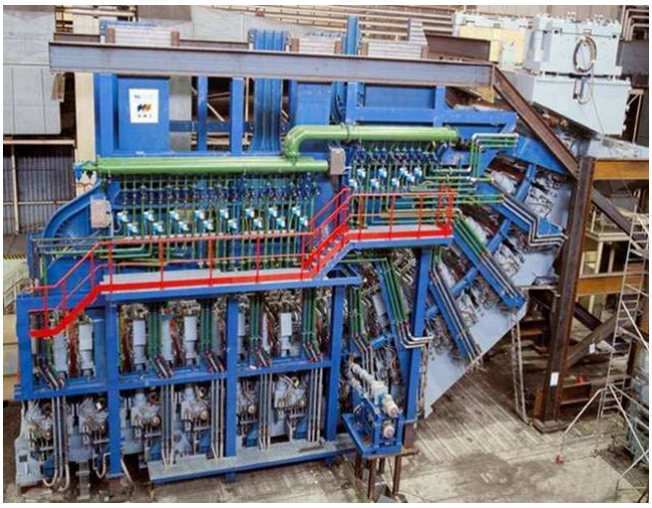

Figure 10: Workshop Integration Testing

Special efforts, innovative solutions and expert project management were therefore necessary to accomplish this major caster modernization, including cold testing, within an extremely tight time schedule. To minimize onsite construction time, pre-assembly of the entire caster and extensive workshop integration tests were carried out in Linz, Austria (Figure 10). The caster could be successfully restarted on October 1, 2002 after a shutdown period of only 20 days. Production was quickly ramped up and single slabs in thicknesses of 160 and 200 mm and twin slabs in a thickness 200 mm could be cast. The targets of this highly challenging upgrading project were fully met (Figure 11).

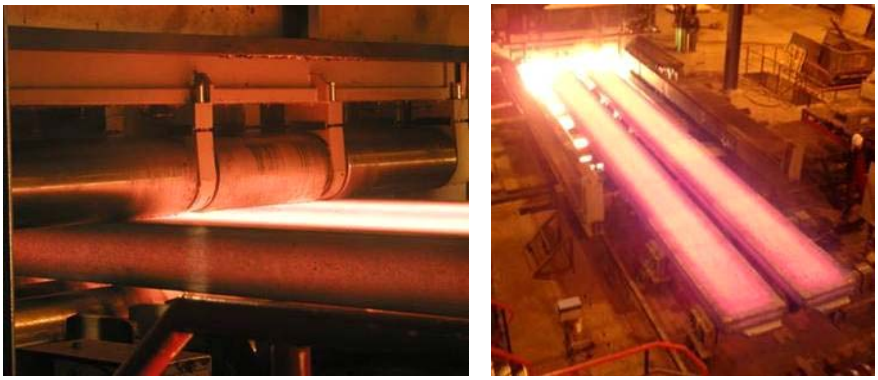

Figure 11: Production of Single and Twin Slabs at Ugine & ALZ, Genk, Belgium

AK Steel Ashland, U.S.A.

On July 1, 2004 the American steel producer AK Steel Ashland awarded VAI a contract for the conversion of their curved-mold caster design to a straight mold design in their single-strand slab caster. The primary objectives were to improve the steel quality and also to enable the casting of interstitial-free (IF) and ultra-low-carbon-steel grades. The LevCon mold-level-control system and the MoldExpert system were installed. The above VAI/Sollac concept was again applied to implement the straight-mold machine design. After only 13 days of caster downtime for the upgrading activities, the machine was restarted. The steel-quality requirements were met and the caster was capable of casting an expanded range of steel grades.

WUHAN Iron & Steel Co., China

VAI was commissioned with a project from WUHAN Iron & Steel Co. to enhance the quality of the cast slabs as well as to increase the operational flexibility of their single-strand slab caster (SMP 2/CC 1). The DynaFlex, LevCon, DynaWidth and DynaGap technological packages were installed, an electromagnetic stirring (EMS) system was installed, the existing curved mold was converted to a straight mold, and the vertical length of the strand-guide system increased.
Already with the first heat following completion of the upgrading activities a total of 36 ladles were cast in sequence at 100% full production capacity (Figure 12). The incidence of non-metallic inclusions could be considerably reduced which eliminated the previous problem of "pencil-pipe defects." Furthermore, the caster productivity was also increased through an extension of supported strand length which made a faster casting speed permissible.

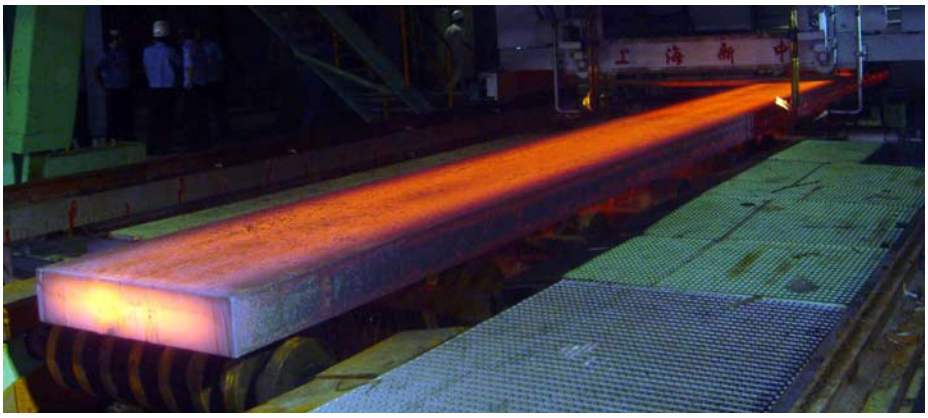

Figure 12: Modernized Slab Caster at Wuhan Iron & Steel Co., China

Customer satisfaction with the achieved results was reflected by the subsequent purchase of two additional 2-strand slab casters from VAI.

ECONOMICAL CONSIDERATIONS

Costs for an upgrading project can be basically summarized as the investment costs, the accrued costs resulting from the related caster downtime as well as the costs arising in connection with a reduced caster productivity during the ramp-up period. The return-on-investment is a function of the improved revenues which result after the resumption of normal casting operations upon completion of the upgrading activities. This is determined by the increased production capacity, by higher profit margins for higher quality products, or both.

A practical economical calculation model was developed by VAI for evaluating the resulting revenues following caster upgrades. Due to the complexity of a product mix and changing market situations, the product-quality factor is not considered in this model. The evaluated parameters include the fixed and variable costs, steel prices and revenues, production figures (before and after upgrading), shutdown time, ramp-up time and the investment itself.

An analysis of various examples of different times that are required for a plant shutdown and the subsequent commissioning/ramp-up period gives a strong indication of the potential revenue benefit that can be achieved. Even with a shorter ramp-up time of just a few days, the resulting revenue improvement can exceed one million U.S. dollars. With a decrease in the shutdown time, this figure is even more impressive.

In Figures 13 and 14 two projects (Project 1 and 2) are compared showing different ramp-up times and shutdown times. Project 1 is depicted by a solid line and Project 2 by a dashed line. The steel price, fixed and variable costs are assumed to be constant for both projects. The increased caster production capacity following upgrading (from 1,500,000 to 2,000,000 t/a) is also the same for both projects.

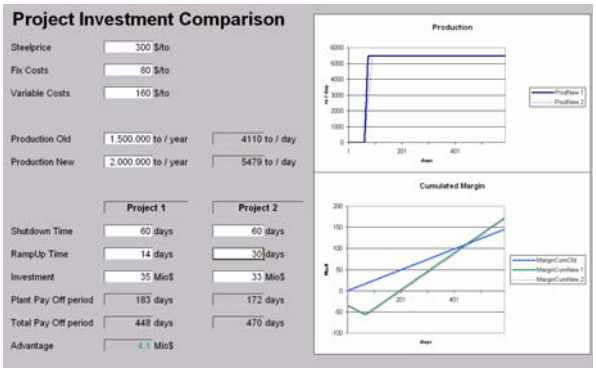

Figure 13: Project Example of Revenue Benefit with Shorter Ramp-up Time Following Upgrading

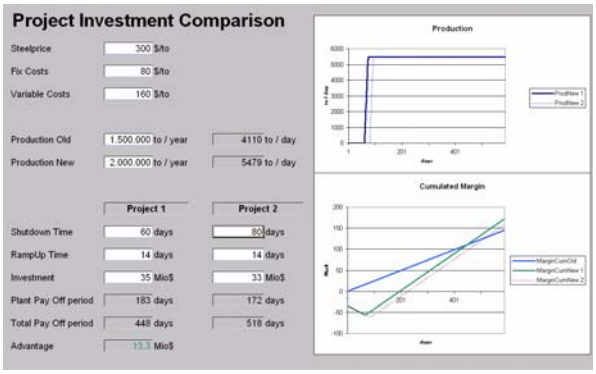

Figure 14: Project Example of Revenue Benefit with Shorter Shutdown Time for Upgrading Activities

In Figure 13 the results for a 14-day and a 30-day ramp-up period are compared. A linear production start-up from zero up to the caster's new nominal production capacity is assumed, and the shutdown time is kept contact in both cases (60 days). For Project 1 with a faster start-up curve, a revenue benefit of U.S.$ 4.1 million could be calculated.
In Figure 14, a 60-day shutdown time is assumed for Project 1 and an 80-day shutdown time for Project 2. In this case, the ramp-up time is assumed to be the same. A surprisingly high revenue benefit results with the shorter shutdown time for Project 1, which was calculated at U.S.$ 13 million! It goes without saying that a shorter ramp-up period in combination with a shorter caster shutdown period would make the results even more impressive.
This project example clearly underlines the major revenue benefit that the installation of connect & cast technological packages can have on shortening the total caster shutdown time. Furthermore, it is clear that extensive component and system testing in the workshop prior to delivery can also have a major impact on shortening the total ramp-up period, again, with the corresponding improvement in the revenue benefit.

CONCLUDING REMARKS

Since the introduction of technological packages in the early 1990s, VAI has modernized a total of 180 casters, incorporating various technological packages into of all types of caster machines producing the complete range of carbon, stainless and special-steel grades. Decisive improvements in caster productivity, product quality, operational flexibility and profitability were the results. In the year 2005 alone, the advantages achieved through the application of technological packages could be demonstrated on the basis of a total of 31 slab and bloom/beam-blank continuous-casting-machine start-ups (new machines and upgrades) in 12 countries worldwide.
As shown by a specially developed economic calculation model, the highest revenue benefit can be achieved in a caster upgrading project when both the caster downtime for upgrading as well as the start-up curve can be kept as short as possible.
Thus, the importance of applying connect & cast technological packages towards meeting the goals of caster upgrades cannot be overestimated.