PROGRAMMING THE CONTINUOUS CASTING AT VALLOUREC & MANNESMAN BRAZIL (V&M): A SEAMLESS TUBES INDUSTRY[1]

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Abstract

The process of going from iron ore to steel pipes involves many operations. Molten metal is produced from iron ore and is purified to obtain molten steel. After a refinement phase, the molten steel is poured into a moulder and takes on a solid form. At last, the semi-finished steel pieces are carried out to selected operations in order to meet customers' final specifications for dimension, surface finish and mechanical properties. The bottleneck of the production line lies in the continuous casting process. The smallest element of this process is a batch. A sequence of batches defines a lot. In between lots the mould gauge is changed. V&M decides the batches' steel grades to produce billets considering their gauges, lengths and demands. We describe the system PROA inserted to V&M's Brazil decision process. Information flow and the production process changes are addressed. The new process still relies on the planner to decide unquantifiable matters, such as the impact of the delaying an order or when to produce to stock. The new process is agile and more stable relying much less on the planner at work. The billets excess is now close to zero.

Key words: Continuous casting; Decision support; Optimization.

PROGRAMAÇÃO DO LINGOTAMENTO CONTÍNUO NA VALLOUREC E MANNESMAN BRAZIL (V&M): UMA INDÚSTRIA DE TUBOS SEM COSTURA

Resumo

O processo de transformação de minério de ferro em tubos de aço envolve várias operações. A partir do minério de ferro se obtém o ferro gusa em estado líquido que é processado para a obtenção do aço com as características de grau e composição adequados. Depois de uma fase de refino, este aço é despejado no distribuidor, passa pelo cartucho e se solidifica. As barras de aço geradas seguem para operações específicas para incorporar as características desejadas pelo consumidor final, que são as dimensões, o acabamento da superfície e propriedades mecânicas. O gargalo da produção é o processo de lingotamento contínuo na aciaria. A unidade mínima é uma panela de aço, ou "corrida", e às corridas consecutivas entre cada troca do distribuidor denomina-se "seqüencial". A V&M precisa decidir os graus e composições das corridas para atender a demanda considerando as respectivas bitolas, comprimentos e quantidades. O sistema PROA incorporado ao processo de decisão é descrito. As mudanças no processo e no fluxo de informações são tratadas. O processo ainda depende do planejador de várias formas, mas é ágil e sobrecarrega muito menos. A sobra de barras-mãe produzidas caiu para quase zero.

Palavras-chave: Lingotamento contínuo; Apoio à decisão; Otimização.

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2 *Vallourec & Mannesman*
3 *GAPSO Tecnologia da Decisão*

1 INTRODUCTION

The process of going from iron ore to steel pipes involves many operations. Molten metal is produced from iron ore and is purified to obtain molten steel. After a refinement phase, the molten steel is poured into a moulder and takes on a solid form. At last, the semi-finished steel pieces are carried out to selected operations in order to meet customers' final specifications for dimension, surface finish and mechanical properties. The bottleneck of the production line lies in the continuous casting process (Figure 1).

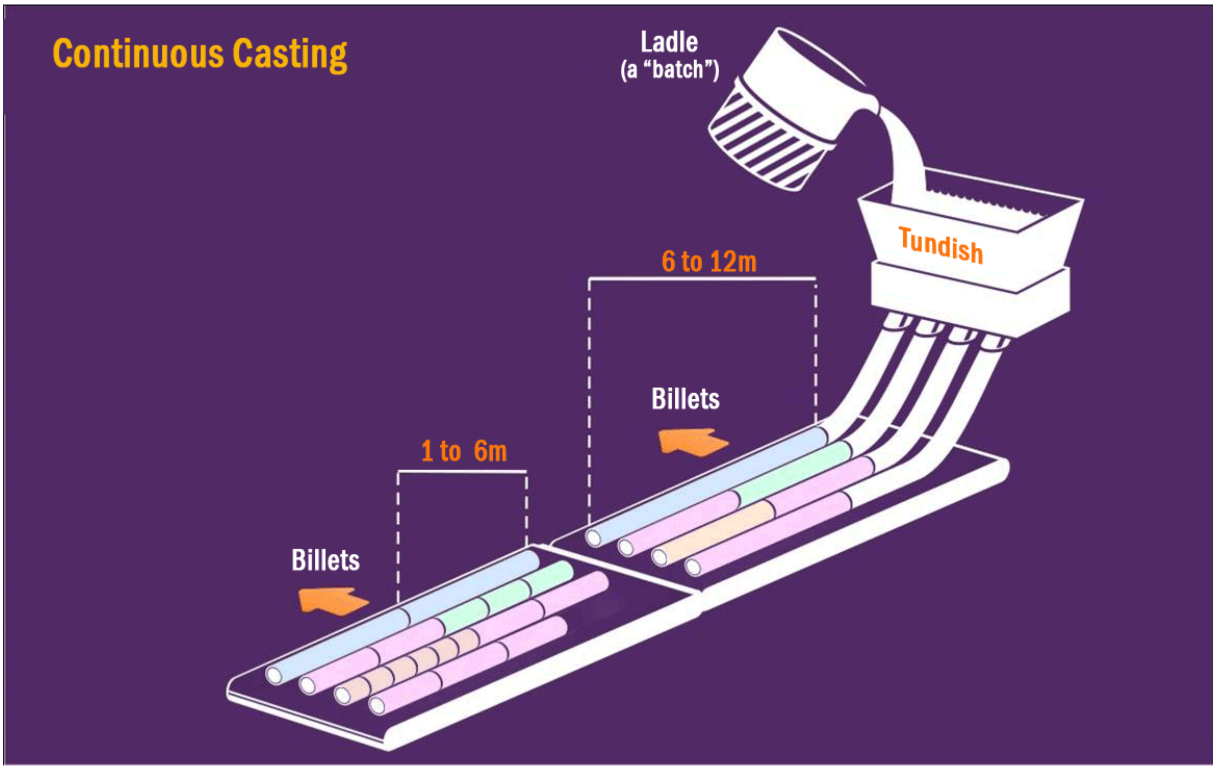

Figure 1: Production process

The smallest element of this process is a batch, which takes about one hour to be casted. In a batch, a ladle, which is a heat resistant bucket used to transport liquid metal, corresponds to this minimum production unit. In the beginning of continuous casting, the ladle is filled with uniform molten steel coming from the refining phase. The process begins when the ladle content is dipped out into the tundish, which works as a funnel providing constant flow of liquid steel to the mould. Since the molten metal can not lose heat before the casting, the tundish must be hot enough to maintain its temperature. From the tundish, the liquid steel is then poured into the mould (casting process) and is solidified forming one or more continuous steel streams of the same shape. While these streams flow, their extremities are cut in order to obtain semi-finished steel pieces, called billets, blooms or slabs (depending on size and shape). The continuous casting process has to meet extremely strict requirements of flow continuity and temperature to guarantee the quality of its final product. The tundish must be heated before being used, since the molten steel must maintain its temperature. To reduce setup times and operational costs with this heating phase, the tundish can be reused a few times as long as it does not become empty. In doing so, part of the content of consecutive ladles are blended in it. Thus, consecutive ladles must have similar grades (chemical compositions) and the same

shape. Each ladle of steel submitted to this process is identified as a batch and the sequence of batches poured by the same tundish is defined as a lot. A lot may have from 5 to 15 batches. In between lots the mould gauge is changed. The main V&M planners' decisions are to specify the batches' steel grades to produce billets considering their gauges, lengths and demand orders. These decisions must consider the due dates of the demands and how the billets will be cut to fulfill them.
The decision process used in V&M Brazil for its continuous casting programming is presented, as well as how the decision support system PROA (an acronym for Optimized Steel Programming in Portuguese) is used. Regarding the algorithms inside PROA, it is interesting to remark that deciding the steel grades considering only the grade variation and lot related constraints to meet the orders weight for specific grades and their due dates may lead to quasi-optimal batch choices. These choices are used to determine the whole production plan, specifying the gauges and the sizes of the billets. This technique may be seen as a hierarchic decomposition of the problem.
There are many works about the steel production line and the continuous casting process. Distinct scheduling problems are addressed by Pacciarelli and Pranzo(1) and Harjunkoski and Grossmann.(2) The optimization of thermal and metallurgical conditions during the casting process was studied by Santos, Spim and Garcia.(3) Chang, Chang e Hong(4) worked on a lot grouping algorithm for the continuous casting process. Dutta and Fourer(5) provide an extensive survey on the use of mathematical programming in steel industries world wide.
This text is organized as follows. The next section describes the characteristics of the continuous casting at V&M Brazil. Section 3 presents the main features of the decision support system PROA. This section is also dedicated to the information flow and the production process changes. Section 4 discusses the decision problems that PROA has to solve and the solution approach it uses. Last section draws some conclusions.

2 CONTINUOUS CASTING AT V&M BRAZIL

Vallourec & Mannesman at Barreiro, Belo Horizonte, Brazil, produces seamless tubes for all sorts of purposes within the oil & gas, automotive, industrial and civil construction sectors. The production flow of this plant works as follows: client orders are directly forwarded to the finishing lines departments; each department organizes its own production schedule; based on the schedules, these departments make requests of unfinished steel billets to the internal steel mill.
The steel mill is responsible for all stages of steel production up to the continuous casting process. Comparing to other steel industries, the main distinct aspect of this mill is the diversity of its demands. The internal requests range from just a single 1-ton steel billet to hundreds of them (one batch has approximately 72 tons of steel). The cylindrical billets can have 3 distinct gauges (diameter) and lengths varying between 1 and 12 meters. Besides, there are about 400 steel grades. With this variety of requests and, consequently, so many sorts of batches to be produced, an enormous effort to make good use of production resources is necessary. The bottleneck of the production line in this industry lies in the continuous casting process. Each batch needs almost one hour to be casted. Two tundishes can be handled at a time, one in the heating phase and the other in use. However, as heating is a slow process, each lot must have at least 5 batches so that production pauses lead to an acceptable productivity. Changes of the mould gauge stop the

production for at least 3 hours. Thus, it is desirable to put as many batches as possible in each lot and to group lots with the same gauge. Lot patterns define sets of grades that can be in the same lot and also in which order they shall appear in the casting process. The patterns are necessary to guarantee that only similar grades are poured in the same tundish. Even though, when parts of consecutive batches are blended in the tundish, their steel can not be classified as neither of the mixed grades. The billets composed by those mixed grades are called transition billets. A transition billet can only be used to attend a demand if both grades can be used separately to attend it. If no demand can be attended by those mixed grades, excess billets are produced and stored in the steel mill inventory.
Many operational constraints must be considered, among them:

- The length of billets cut directly from the steel stream during the casting phase must be between 7 and 12 meters. Requested billets with shorter lengths have to be grouped in longer billets, which are split later. In order to prevent mistakes, requested billets are called final billets and billets cut during casting are called intermediate billets. An intermediate billet can only contain final billets of the same demand;
- Regarding length and demand, each batch can have at most 9 distinct intermediate billets;
- Final billets contained in transition intermediate billets can not have the same length than final billets of the middle of the batch, unless both can be attended by the mixed grades.

The production planning of the steel mill defines the gauge changes, the sequence of lots and the production of each lot for the next few days.

3 DECISION PROCESS AND THE SYSTEM PROA

Programming the continuous casting at V&M Brazil is done following a decision process that was conceived through many years of operations. The planning team is small, about five persons, and during the past has changed very little. The modus operandi reached consists of keeping a simplified production plan for the next two weeks and to daily plan the details of the continuous casting for the next two or three days. Due to a continuous arrival of new demands with spread due dates, this production plan needs to be often revised and its simplifications correspond to consider only that the steel quantity needed fulfills the required demand orders and to put batches of similar steel (and same gauges) together in lots. The detailed plan amounts to specify how the grades and compositions of the steel in each batch of a lot. Also, this detailed plan needs to determine how to cut the billets so that the demand is met.
Previously to having PROA incorporated to the process, the construction of a production plan demanded a long and careful work of several hours. The current process revises the production plan for the next two weeks every other day. PROA allows the planners to have a first production plan built in a few minutes, having time to analyze, change or update the used information.
Running the continuous casting requires to have the lots and the batches specified. Once the demand is assigned to a lot of a determined number of batches, a more detailed plan is needed. The sequence of grades and compositions of the steel must be compatible, and they must also satisfy the demand with a grade as close as possible to the one specified for that demand. Further, the billets produced must

allow a cutting the meets the quantities with an excess that is as small as possible. This is a cumbersome decision, involving many details.
To give a feel of this planning activity and of the features of PROA, Figure 2 below presents the planning interface. The window on the left shows the information tree associated to a planning scenario. The scenario is defined by the input data, the top sub-tree, where all characteristics available at V&M Brazil are present, together with the demand orders to be met and the steel mill operations. This includes the maintenance stops, resources availability and other relevant information. The bottom sub-tree lists the possible outputs: the production plan, the batches and lots, the reports on the demand fulfillment. The window on the right has two reports superposed. The one in the front shows the demand orders and how they will be attended (steel grade and other characteristics). The one behind is a production plan.

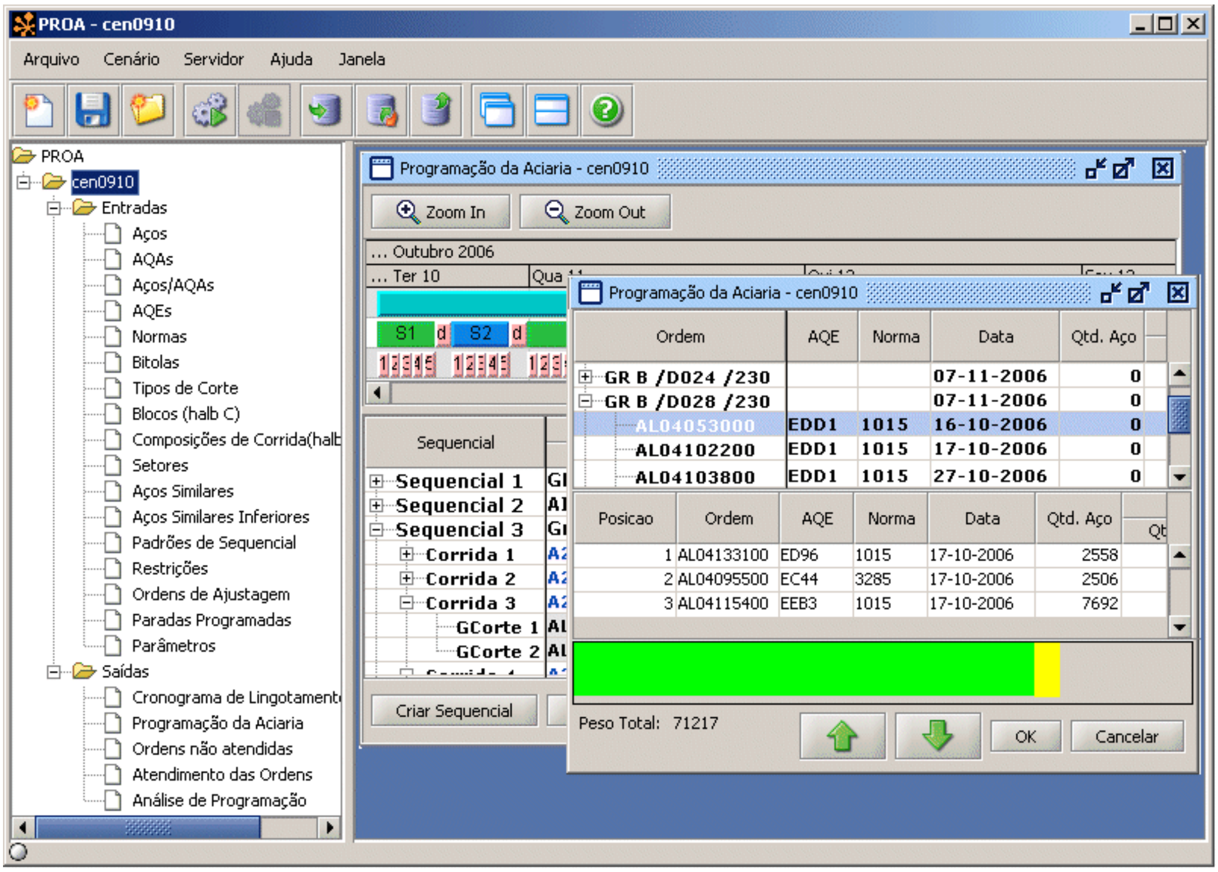

Figure 2: PROA planning interface

A production plan is presented in more detail in the right window of Figure 3. The horizontal (green) bars separated by a “d” represent the lots, each number below these bars is associated to a batch. Underneath these bars the lots are completely specified. The steel grades and compositions of the batches and the demands orders covered by each batch are also listed.

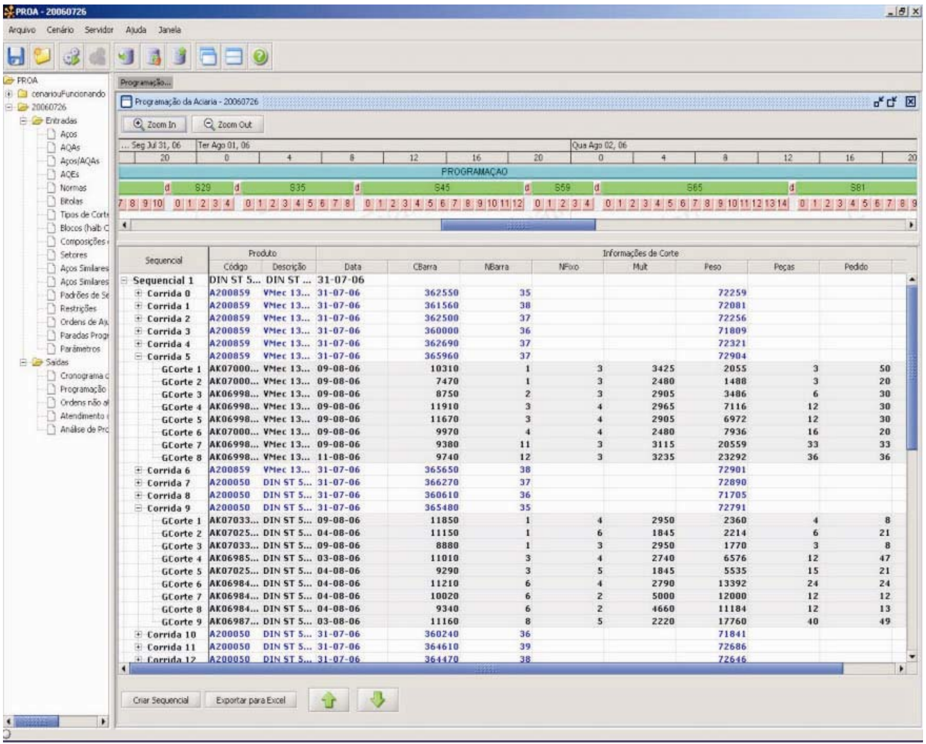

Figure 3: Representation of a production plan

The decision process with PROA still relies on the planner to decide unquantifiable matters, such as the impact of the delaying an order or when to produce to stock, and to feed the system with information still unavailable in the company information systems. To this, the interfaces above are of great help. Nevertheless, the process is agile and more stable relying much less on the planner at work.

4 THE DECISION PROBLEMS AND ALGORITHMS

One might believe that the decision process present in the continuous casting programming of V&M Brazil should be tackled by an algorithm aiming directly at the global optimum, and that it would greatly benefit from this strategy. Although, as will be shown in this section, there might still be some small benefits in using this strategy, one must first consider how it would fit into the steel mill decision process. First, it is clear that a production plan must be devised and revised often. For this if a global optimum is pursued, this production plan should consider all the continuous casting programming details. Consequently, there would be no need to later specify the details of the batches and how they fit into the lots and which orders they meet. This is so, since all is done when devising the production plan.

The first difficulty with this approach is that the methodology available today to solve this huge optimization problem to optimality, although improving each day, still requires more than several hours. The second is that trying to find a continuous casting programming that may not be the optimal detailed one, but is detailed close to the optimal programming, seems be as tough as finding the optimal one.

At this point, one will see that it is possible to learn from the years of experience in devising the continuous casting by hand. The approach used inside the PROA system consists in following the steps of the planners that developed the decision modus operandi at V&M Brazil. The steps of the decision process give rise to two problems corresponding to devising the production plan and to determining the batches in the lots. These steps suggest a decomposition of the problem in which it assumes that the grouping the demand orders into lots has a higher hierarchy level than specifying the steel grades and compositions and how the billets are cut to meet the demand. These two problems are described in the following subsections.

4.1 Cluster of the Orders into Lots

The first problem consists of clustering the demands into lots. A lot must have demand orders of a same gauge and similar steel grade and composition. A lot pattern specifies the different grades and compositions of steel that are allowed to belong to a same lot and the order that the grades of steel change from batch to batch inside a lot.
Given a list of demand orders together with their due dates and their characteristics, the objective is to cluster the orders in lot patterns such that the due dates that are not met are minimized, the lots have as many batches as possible (less than 15) and all the operational constraints are satisfied.

4.2 Steel Grade Assignment and Cutting Billets

This second problem corresponds to the planning of the production of one lot of a specific lot pattern and gauge.
Given the number of batches, the grades allowed in the lot pattern, a set of demands and, for each demand, the subset of grades by which it can be attended, the problem consists in defining the number of batches to be produced, selecting the steel grade of each batch and indicating the sequence of billets to be produced in each batch. The following constraints shall be satisfied: demand requests can only be attended by billets composed of the indicated grades and the length of each batch can not be exceeded. Furthermore, all operational constraints aforementioned must be respected.

4.3 Quality of the Continuous Casting Programming with PROA

The combined goal of solving the two problems above sequentially is to reach the global optimal continuous casting programming. In other words, to devise a plan that attends the requests with earliest due dates, reduces production costs and to minimizes the production of excess or unused billets.
The quality of the plans built by PROA solving the two problems was evaluated by comparing the global solution value obtained to an estimate of the best possible solution value. This estimate is guaranteed to be smaller than the global optimal plan. The comparison is presented in Figure 4. This figure presents a graph where scale of the vertical axis is a measure of the total cost of the devised plan. Therefore, the smaller is the bar, better the solution is. Each set of three columns corresponds to a continuous casting programming scenario at V&M Brazil. The left column of the three correspond to the value of the solution of the first problem, which considers less constraints and less details, and therefore has always a smaller value. The column in the middle corresponds to the estimated of the best (smallest) cost a plan may have in the considered scenario. Finally, the right column corresponds to the complete detailed plan obtained by the system PROA.

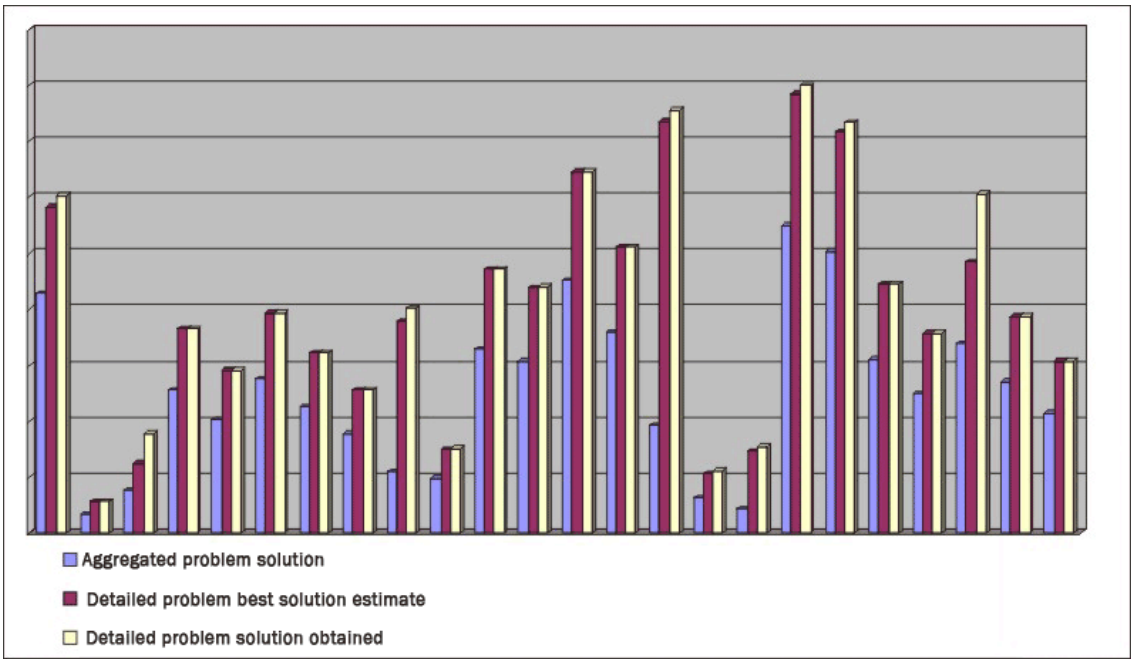

Figure 4: Quality of PROA´s proposed plans

Figure 4 suggests that although the global problem is solved in pieces by PROA, it often produces a continuous casting programming that is close to the best possible.

5 CONCLUSION

This text described the decision process to provide an agile and improved continuous casting programming in the steel mill of V&M Brazil. A decision support system, PROA, was developed and is operating daily at V&M Brazil since September 2006. The new decision process with PROA still relies on the planner to decide unquantifiable matters, such as the impact of the delaying an order or when to produce to stock, and to feed the system with information still unavailable in the company information systems. This new process is agile and more stable relying much less on the planner at work. The billets excess is now close to zero. The continuous casting production timetable can now be promptly obtained allowing adjustments and a wider communication.
Moreover, this work provided evidence that the planners at V&M Brazil produce consistently very high quality production plans that can be carried out. Arrivals of new demands or unpredicted failures, require only a revision of the steel mill program that can be done in a very shot time.

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