# QUALITY OPTIMIZATION SYSTEM FOR PELLETS SHIPPING AT VALE[1]

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## Abstract

The decision support system SOP3-Quality, in use at VALE, supports the planning of pellet shipment loading. The quality guarantee team has the task of planning the pellets stockpiles that shall be reclaimed for each shipment. The chemical, physical and metallurgical properties of each stockpile are known. The objective is to perform ship loading operation minimizing quality deviation of the available stacked pellets. The iron ore pellet shipment planning is done following a sequence of steps. For each step there is an algorithm capable of providing supporting decision suggestions. The first step amounts to determine, for each shipment, which of the pellet stockpiles have properties that are adequate to be shipped according to client's specification. The second step consists of proposing quantities of the selected stockpiles that fulfill each shipment loading. A final step decides the order in which the pellets are to be reclaimed. The system automates and formalizes the iron ore pellet ship loading process. It determines the quantities from each stockpile that will reclaimed for each customer cargo. The mathematical models supporting the implemented optimization algorithms were able to accurately represent the pellet business knowledge.

**Key words:** Iron ore pellet; Demand fulfillment; Decision support; Optimization.

### OTIMIZAÇÃO DO ATENDIMENTO DE CLIENTES DE PELOTAS DA VALE

**Resumo**

O sistema de apoio à decisão SOP3-Qualidade, em uso na VALE, otimiza o planejamento dos embarques de pelotas de minério de ferro. A equipe de planejadores tem a tarefa de selecionar as pilhas de pelotas nos estoques que serão recuperadas em cada embarque. As propriedades químicas, físicas e metalúrgicas das pelotas nas pilhas são conhecidas. O objetivo é selecionar as pilhas de forma a garantir uma qualidade de atendimento de acordo com a especificação do cliente e minimizar desvios das propriedades das pelotas que serão embarcadas. Este planejamento é realizado através de uma sequência de etapas apoiadas por algoritmos que fornecem sugestões para o processo decisório. A primeira etapa determina, para cada embarque, quais estoques de pelotas têm o produto objetivado e as propriedades de acordo com o especificado para o cliente. A segunda etapa consiste na determinação das quantidades de pelotas que serão extraídas de cada estoque selecionado. A etapa final determina a ordem na qual as pelotas serão recuperadas. O sistema automatiza e formaliza o processo de atendimento de demanda de pelotas, o que permite mais agilidade na determinação das quantidades de cada estoque que irão compor cada embarque. Os modelos matemáticos utilizados para apoiar os algoritmos de otimização implementados foram capazes de representar com precisão as regras de negócio.

**Palavras-chave:** Pelota de minério de ferro; Atendimento de demanda; Apoio à decisão; Otimização.

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## 1 INTRODUCTION

At VALE, iron ore is the core of its portfolio, keeping up with high global demand and being exported to the four corners of the globe. The pellets are small aglomerates of iron ore that are used in the steel manufacturing industry.

The quality of iron ore pellets is dependent on three main factors: chemical (the composition of the ore – Fe, $SiO_2$, $Al_2O_3$, P, Mn…), physical (abrasion, compression strength, size distribution…) and metallurgical (swelling, sticking, reduction degree…) which affect performance and productivity of the furnaces.

In short, the iron ore and other raw materials, carried out of the VALE's mines, are transported to pelletizing plants. Inside these plants, after a sequence of procedures, the iron ore is turned into pellets with an average size of 12.5 mm in diameter. The iron ore pellets are carried by conveyor belts from pelletizing plants to the stockpiles, where stacker machines are used to organize the pellets within yard stakes forming piles of iron ore pellets.

Finally, according to the customers demand, the iron ore pellets are recovered from stockpiles, by reclaimer machines, and loaded on ships (Figure 1).

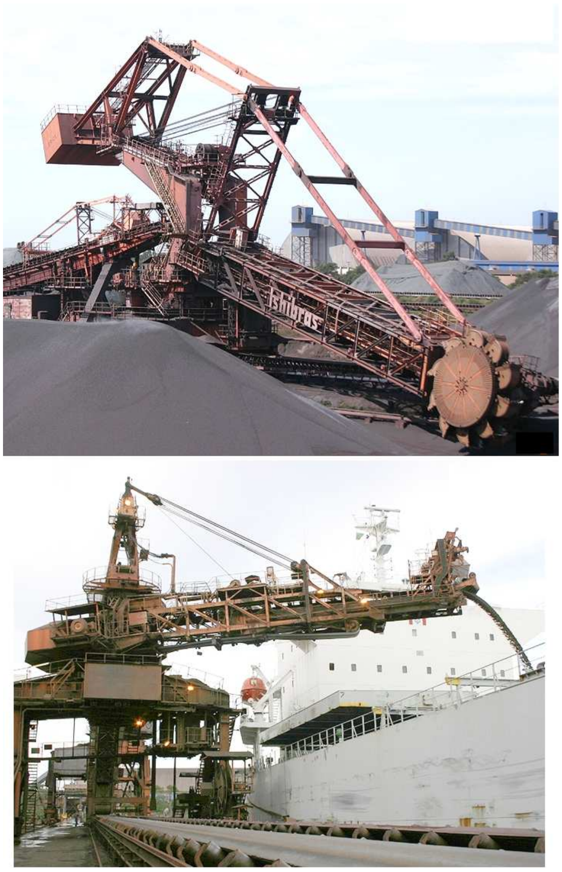


**Figure 1.** The iron ore pellets are recovered from stockpiles, by reclaimer machines, and loaded on ships.

Within this process, the planning of pellet shipment fulfillment is performed by VALE's staff of planners that has the task of programming the yard sections of the iron ore pellet stockpiles that shall be reclaimed to form each shipment.

The chemical, physical and metallurgical properties at each stockyard stake are known. The objective is to load the vessels with a minimum quality deviation possible in order to meet the customer specification.

With the system SOP3-Quality, the iron ore pellet shipment planning is done by following a sequence of steps. For each step there is an algorithm capable of providing supporting decision suggestions. The first step amounts to determine, for each shipment, which of the pellet stockpiles have the aimed product quality. The second step consists of proposing quantities of the selected stockpiles that fulfill each shipment. A final step decides the order in which the pellets are to be reclaimed. Available reports show how much the planned final shipment adheres to the specifications, and what was effectively shipped.

This paper is organized as follows. The next section gives a view of the process of planning the iron ore pellet ship loading at VALE. Section 3 presents the main features of the decision support system SOP3-Quality. Section 4 discusses the decision problems that SOP3-Quality has to solve and the solution approach it uses. Last section draws some conclusions.

## 2 A VIEW OF THE PROCESS

The planning is done daily according to shipments scheduling. The information upon pellets vessels shedulling is the starting point of it. In short, a demand is a quantity (in tons) of a given type of iron ore pellets for a given customer to be loaded on a vessel. Moreover, these pellets must comply with a specification that determines the minimum and maximum quality specified in terms of its chemical, physical and metallurgical properties.

The operation planner first considers the demands that are to be met in the current day. The quantities and the pellet types of the demands are the basic information. Next, this planner selects the stockpiles in the yard that can be chosen to fulfill each one of the current day.

The operation planner needs then to analyze the reports on the chosen stockpiles. They contain their quality properties and quantities. The reports show the results of sample analysis from each stockpile on a daily basis of the pellet production process.

For each demand of a client the planner must determine the amount of pellets from the stockpiles that will be needed to meet the contractual specified properties and total quantity. However, this choice must consider a list of operational constraints. We describe a few:

- Some yards have an orientation which must be followed when reclaiming the pellets (from the lower numbered yard stakes to the higher numbered or vice-versa). Other yards may reclaim in both orientations;
- Yards have a pre-defined lowest (or higher) starting stake for reclaiming in the lower to higher stake orientation. For instance, a yard with eighty yard stakes may have as lowest possible starting yard stake number fifteen according to the reclaiming direction in the lower-higher orientation; this occurs due to yard operational restrictions;
- The yard stake that ends a reclaiming operation must have an empty area between this yard stake and the next one. If the orientation is lower-higher and the final yard stake is numbered sixteen, then the area between yard stakes sixteen and seventeen must be kept empty;
- The port yards have higher priority than the ones at the production plants when they are both considered to meet a given demand;
- Some interval of yard stakes in the yards may have a maximum quantity that may be reclaimed from them.

The chosen plan that specifies the quantities to be reclaimed from each stockpile is then considered as the ship loading plan. The order in which they are to be loaded is to be decided.

This loading plan is then performed by the port operation team. During the ship loading process samples are taken and the quality properties are then re-analyzed in order to allow a more precise quality evaluation of the shipment.

Finally, with the reports on the analysis from samples, the planner compares the properties of the final loading with the ones contractually required to meet the demand. Figure 2, below, depicts ship loading process.

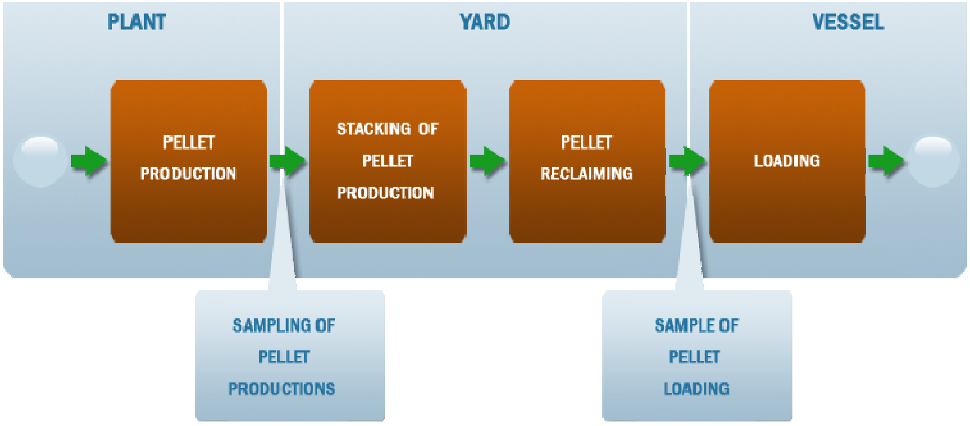



**Figure 1.** The ship loading process.

## 3 THE SYSTEM

SOP3-Quality allows the planners to work on scenarios. A planning activity starts by specifying the information required to plan the current day. The demands (shipping scheduling) to be met and the quantities and quality properties of the pellets in the stockpiles of the yards describe a planning condition of the moment.

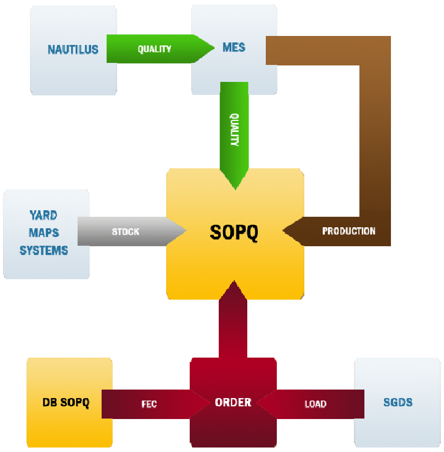
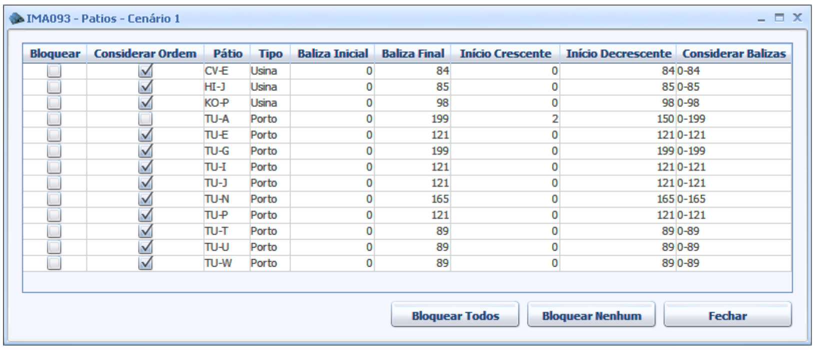



**Figure 2.** SOP3-Quality system and its data connection mechanisms with transactional systems at VALE.

The data required to specify a loading scheme is obtained from several transactional systems at VALE. The SGDS (Demand and Supply Management System), the MES-Pelletizing (Manufacturing Enterprise System of the Pellet Production Plants), and the Yard Maps System, are some of them. To ease the planning activity using SOP3-Qualityde, several data connection mechanisms were made available. Web services and database views are among the mechanisms connecting SOP3-Quality to those transactional systems (see Figure 3).

The planning process starts with the selection of one or more demands to be met. Once the demands are determined in the system, it creates a scenario that contains all the information required, including the complete status of the stockyard considering product availability in terms of quality.

Next, the planner may configure the operational constraints to be considered. Reclaiming constraints and priorities are defined, for instance. Figure 4 presents a SOP3-Quality screen where the planner chooses the yards that may be considered for loading as well as the allowed reclaiming orientations.

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| ☐ | ☑ | HI-J | Usina | 0 | 85 | 0 | 85 | 0-85 |
| ☐ | ☑ | KO-P | Usina | 0 | 98 | 0 | 98 | 0-98 |
| ☐ | ☐ | TU-A | Porto | 0 | 199 | 2 | 150 | 0-199 |
| ☐ | ☑ | TU-E | Porto | 0 | 121 | 0 | 121 | 0-121 |
| ☐ | ☑ | TU-G | Porto | 0 | 199 | 0 | 199 | 0-199 |
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| ☐ | ☑ | TU-J | Porto | 0 | 121 | 0 | 121 | 0-121 |
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**Figure 3.** SOP3-Quality screen where the planner chooses the yards that may be considered for loading as well as the allowed reclaiming orientations.

SOP3-Quality allows the visualization of the quantities of pellets in the yards from each production batch. The system also makes geometric calculations (based on the graphical representations of available from the Yard Maps System) that allow the user to access more detailed information on the stockpiles such as the distribution of the quantities along the yard stakes. Figure 5 shows how this information is presented to the planner. This interface of SOP3-Quality permits the planner to manually adjust or correct any of the quantity values. This is so since the information imported from the transactional systems may not be up to date or even incorrect, and the planner may have other more reliable sources of information.

The information above completes the planning scheme. The following step is to perform the simulation using of the SOP3-Quality's mathematical solver. It generates an optimized ship loading plan for the specified demands. The algorithms aim at minimizing the differences of each chemical and physical property of the iron ore between pellet loading and specification, maximizing client satisfaction. Since the mathematical solver considers all operational constraints, it generates a feasible ship loading plan.

The ship loading plan SOP3-Quality can be obtained in two ways: by yard stake and by production batch. Figure 6 presents the SOP3-Quality screen where the loading plan is showed by yard stake. The production batch option allows the user to have access to the quantities of pellets that are to be reclaimed from each batch on each yard for each loading plan. The yard stake plan shows the reclaiming location scheme of each yard as well as the quantities that are to be reclaimed within a pair of yard stakes. The SOP3-Quality plan interface allows the planning user to make changes on the automatic generated plan that is initially presented if necessary.

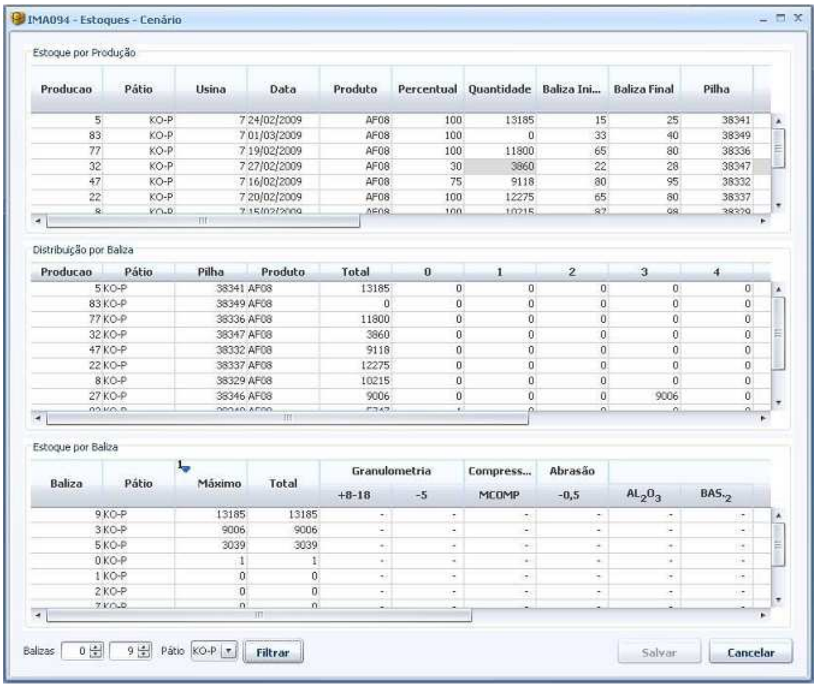


**Figure 4.** SOP3-Quality screen that allows the visualization of the quantities of pellets in the yards from each production batch besides more detailed information on the stockpiles such as the distribution of the quantities along the yard stakes.

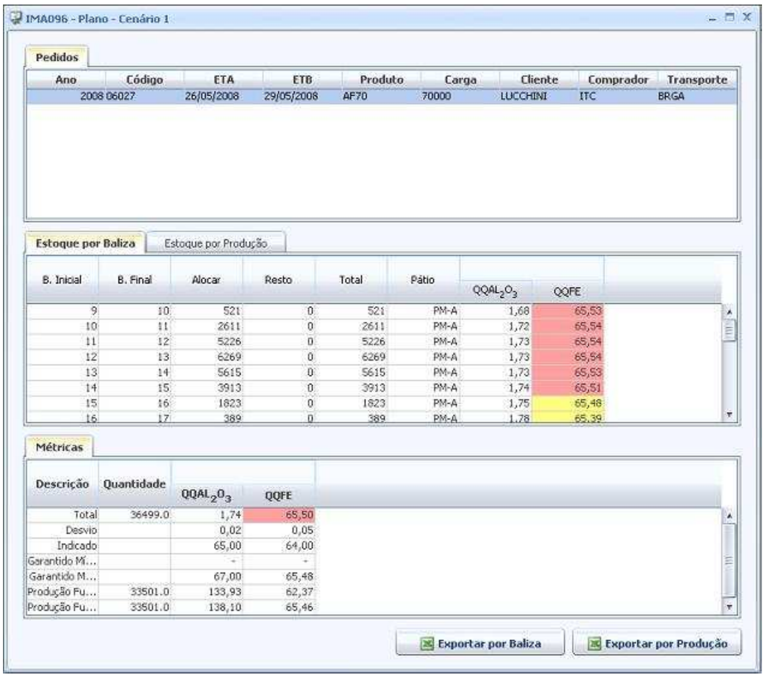


**Figure 5.** SOP3-Quality screen where the loading plan is showed by yard stake.

Finally, SOP3-Quality enables the planner to export the constructed and approved ship loading plan to Microsoft-Excel files. Figure 7 presents a view of those files. They make available several quality metrics of the proposed plan which allows the planner to precisely evaluate its quality.

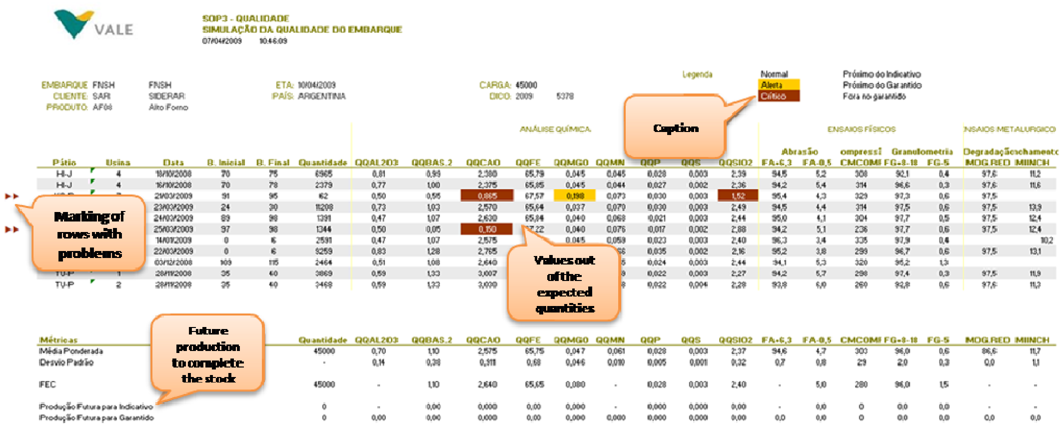


**Figure 6.** Microsoft-Excel file exported from SOP3-Quality system.

## 4 THE DECISION ALGORITHMS

The concepts and ideas behind the algorithms in SOP3-Quality are presented in this section. We recall that the main objective of SOP3-Quality's algorithms is to optimize the quality at iron ore pellet ship loading according to customer specification.

The algorithms that the mathematical solver run to generate the ship loading plans first constructs a Mixed Integer Linear Programming (MIP) model associated to the given scheme. A commercial MIP solver package is used to generate initial quasi-feasible ship loading plans. Next, the solver uses several combinatorial optimization heuristic techniques to obtain feasible plans improving overall quality plan. For this a Genetic Algorithm is applied using an encoded version of the plans produced by the MIP solver. Techniques such as, or similar to, Local Branching are then applied.

The MIP model describes the planning problem over decision variables that account to several local decisions. These are the assignment of the yard sections to the demands and the associated sense in which the stakes are reclaimed. Also, another decision is the volume from a given yard section that is taken for the assigned demand. Auxiliary variables are used to control whether or not the total volume in a yard section is used to fulfill a demand, to limit the number of yard sections that can be used in this task and the number of demands that can receive ore from a given yard section.

All these variables together with ones that account for possibly unfulfilled demands are used in constraints that describe the rules and conditions that must be met when determining how the demands should be fulfilled with the ore present in the yards. Those include the obligation to reclaim continuously the yard sections from a yard. To give the solver a flavor of human decision, the concept of ideal percentage to be used in the fulfillment of a demand is used. Also, there is a soft lower and upper bounds on these limits. There are penalties for not meeting the soft limits, but the hard limits must always be satisfied.

The running time of the resulting algorithm is almost always less than ten minutes, as required. The solver was tuned to accomplish this running time in such a way the it is able to find optimal solutions in almost every run.

## 5 CONCLUSION

This paper described the decision process to obtain an optimized loading plan of iron ore pellet ship loading. A decision support system, SOP3-Quality, was developed and is operating daily at VALE since April 2009. This system automated and formalized the iron ore pellet planning loading process. This consists basically to determine the quantities from each stockpile that will compose each customer shipment demand. Therefore, the shipment loading decision making was optimized in terms of time consuming and reliability in order to guarantee client satisfaction. The mathematical models supporting the implemented optimization algorithms were able to accurately represent the pellet business knowledge. Furthermore, the tool usability allowed easy checking of the performed plan.