INTEGRATED IRON ORE PORT SUPPLY CHAIN LOGISTICS AT VALE[1]

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Abstract

The Integrated Port Optimization System (SIOP), in use at VALE, supports and integrates decisions taken by the four planning groups that manage the vessel queue, port yard, train queue and car dumper in each of the three productive systems operated by VALE. Decisions range from planning the use of trains to the berthing and loading of vessels. SIOP is powered by algorithms designed to: choose and schedule a berth for each vessel; designate which area in the port yard stores stockpiles for each shipment; decide which stockpile is used in the loading of each ship at each instant in time and which resources are used; determine for each train the type of iron ore it carries and which shipment it meets; and, lastly, choose the car dumper, the equipments needed and the stockpile each block of cars will be dumped to. The four managing groups jointly decide based on the SIOP planning suggestions. SIOP has seven modes that allow generating optimized and integrated plans. Planning can now be done in a few minutes allowing the analysis of several scenarios. User expertise can be used to design improved operations plans that amounts to a more efficient iron ore logistics.

Key words: Iron ore logistics; Integrated planning; Optimization.

LOGÍSTICA INTEGRADA DA CADEIA DE SUPRIMENTOS DE PORTOS DE MINÉRIO DE FERRO NA VALE

Resumo

O Sistema Integrado de Otimização Portuária (SIOP), em uso na VALE, apóia e integra as decisões tomadas pelos quatro grupos de planejamento que gerenciam a fila de navios, o pátio do porto, a fila de trens e o virador de vagões em cada um dos três sistemas produtivos da VALE. As decisões abrangem do uso dos trens à atracação e carregamento dos navios. O SIOP possui algoritmos para decidir: que navio usa que berço e quando; que área do porto armazena que pilhas de minério para que embarques; que pilhas são usadas para carregar que navios em que instantes e com que recursos; que trens carregam que minérios para que embarques; e que virador de vagão vira que lotes para colocar em que pilhas formadas com que recursos. Os quatros grupos de planejamento decidem conjuntamente baseados nas sugestões do SIOP, que possui sete modos de operação para permitir esse planejamento otimizado e integrado. Os planejamentos podem agora ser feitos em alguns minutos, o que permite a análise de vários cenários e o uso do conhecimento dos especialistas para obter planos ainda melhores, resultando numa logística de minério de ferro cuidadosa e eficiente.

Palavras-chave: Logística de minério de ferro; Planejamento integrado; Otimização.

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1 INTRODUCTION

VALE's iron ore comes from three productive systems. The northern system integrates mine, railway and port joining the mineral county of Carajás to the port at Ponta da Madeira, São Luís, Maranhão. The southeast system extracts iron ore from six mining complexes in the state of Minas Gerais that converges to the Vitória-Minas railway which take the iron ore to the Port Complex of Tubarão. The southeast and the northern systems have beneficiation plants and pelletizing plants. Finally, the southern system exports its iron through the ports of Guaíba and Itaguaí.

Iron ore logistics at VALE is widespread. It involves the management of equipments and workers to extract the iron ore from the mines, the transportation and storage requirements for the beneficiation, planning the use of railways and other modals to achieve correct blending to meet demands, the storage in the yards and the loading of the vessels to fulfill the demands and many more crucial maintenance and additional activities.

The present work refers to the iron ore port logistics. It considers the activities in the supply chain that go from the use of trains that bring the iron ore to the loading of vessels at the port. This includes defining which trains bring the iron ore for each demand, which car dumpers unload each block of wagons, where the iron of each demand will be stored in the yard, the conveyor belts to be used to send the ore from the car dumpers to the stackers, where to berth each ship and, finally, the reclaimers and conveyor belts to be used to send the iron ore to the shiploaders.

The planning and operation of the use of the resources to fulfill all the demands is complex and is done by four managing groups at VALE. They are:

The vessel queue group (VQ) plans the berthing of the vessels;

- The train queue group (TQ) deals with the products that are loaded in each train along the planning period;
- The port yard group (PY) manages the iron ore stockpiles that serve train unloading and the loading of the ships;
- The car dumper group (CD) is responsible for assigning the blocks of wagons to the car dumper.

These four groups need to organize their activities so that each one can deal with the operations it manages directly and is also capable of communicating with the other groups in order to produce an integrated plan. This integration is an important factor for reaching the common objective of maximizing the iron ore throughput of the productive system.

The Integrated Port Optimization System (SIOP) allows this communication and provides optimization algorithms aimed at individual and integrated planning activities maximizing the throughput at the port. SIOP algorithms are designed to:

- determine which vessel uses which berth and when;
- designate which area in the port yard stores stockpiles for each shipment;
- decide which stockpile is used in the loading of each ship at each instant in time and which resources are used;
- determine for each train the type of iron ore it carries and which shipment it meets;
- choose the car dumper, the equipments needed, and the stockpile each block of cars will have its iron ore dumped to.

Users in the four managing groups are trained to jointly decide based on SIOP's planning suggestions. Moreover, SIOP meets the important requirement of being

“productive system independent”, which means that every present and future productive system at VALE can use it with no modification.
This text describes SIOP and how it fits into the VALE process of iron ore port logistics.

2 A VIEW OF THE PROCESS

The planning is done continuously for the next 120 days. The information upon the demands is the starting point of it. The arrival of the ships is known with a confidence that diminishes over the planning horizon. For the first three weeks, ETA´s (Estimated Time of Arrival) are already available for the ships. ETA’s for vessels arriving more than four weeks ahead is based on experience and supply contracts to be honored. This information is central for the vessel queue (VQ) and for train queue (TQ) planning. The information on the ships’ arrival allows an independent planning of the two managing groups VQ and TQ. The VQ group will then consider the use of berths and cranes, the tides, the order of arrival of the ships at the port and the demurrage costs to provide a vessel queue. On the other side of the planning, the TQ group determines the use of the available trains for each planning day considering the production capacity of the mines, the transportation capacities and the ETB’s to meet as close as possible the demand due dates.
The planning of the VQ and TQ groups provides the information necessary for the port yard (PY) management group to decide on the placing of the iron ore, the equipments to be used in the creation of the stock piles, and on the loading of the ships. Finally, the car dumper group (CD) foresees trains arriving in the following 48 hours to determine the unloading schedule of the car blocks. Here, the main concern is avoiding that the use of routes of conveyor belts and other equipments block each other, causing delays.
It should be kept in mind that the information for planning is constantly changing. The ETA´s information is updated daily, eventually requiring a full revision of the current operations plan. Inside the productive system, the availability of equipments may not follow what is expected and time arrival of trains and ships may vary considerably. The communications among the managing groups turns out to be a central requirement for keeping the operations as swift as possible. Figure 1, below, depicts the activities dealt by each management group and allows understanding why integration and optimization are important issues regarding effective planning.

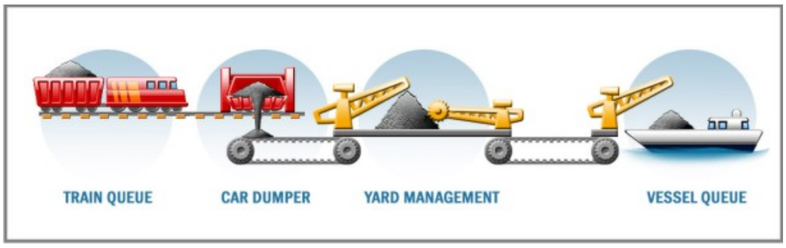

Figure 1: Iron Ore Productive System

To understand the elements that integrate the decisions, we remark that the operations management plans to meet shipment demands by defining an estimated time of berthing (ETB) to each vessel taking into account the ETA, which may be as precise as the lay days depending on how far in the future it is. This is confronted with the estimated date that the required quality and quantity of iron ore will be available at the port. This date is denoted as DCP at VALE. Ships can only berth on the DCP or afterwards, which turns the synchronization of ETA's and associated DCP's an important measure of the efficiency of the productive system. Deciding properly and continuously the iron ore that is to be sent by the trains along the planning period cannot be done without an adequate synchronization with the use of the port yard resources. In the same way, the placing of the iron ore stock piles in the yards and choice of berths to the ships may turn the car dumper operations into an easy or a difficult task.

3 THE SYSTEM

One of the challenges to overcome when developing such a system is finding how the responsibilities of each managing group should interface with the ones of the other groups. This amounts to not only devising where the decisions of one group affect the ones by the others, but to define and to model the decision problems that derive from the global decision process. This was achieved by providing a system where each group can deal with all of its specific information and also have a view of the global system. Additionally, operation modes were conceived to allow several levels of integration of the decision of one group with the decisions of other groups.
We describe the views of SIOP for each managing group. This is followed by a discussion of SIOP’s seven modes of operation.

3.1 The Vessel Queue (VQ)

The VQ makes the decisions related to the allocation of the vessels to berths. SIOP’s VQ takes into account the following elements: demurrage (value within and out of the lay time, value for iron ore quantity variation), sea currents (speed along each day), tides (height along each day), embark (time to take out the ballast, draught, width, length, lay days, ETA, iron ore product and quantity), tug boats required in each phase of berthing, use of channels and piers, maneuvering restrictions due to tide, currents and deadweight, types of iron ore that can be loaded, duration of berthing phases and shiploaders operation rates and maintenance stops.
The user has access to all this information for analysis and modification. Besides the use for the daily operations, the system allows scenario evaluations that can be shared within or among management groups. Carrying out the routine of operations planning and execution requires more than the automated planning present in SIOP. The operator may need to change SIOP´s planning suggestions due to exogenous reasons. These changes must be done with the full view of the whole operations plan. This is achieved by interfaces that allow graphically changing the time of berth or the order.

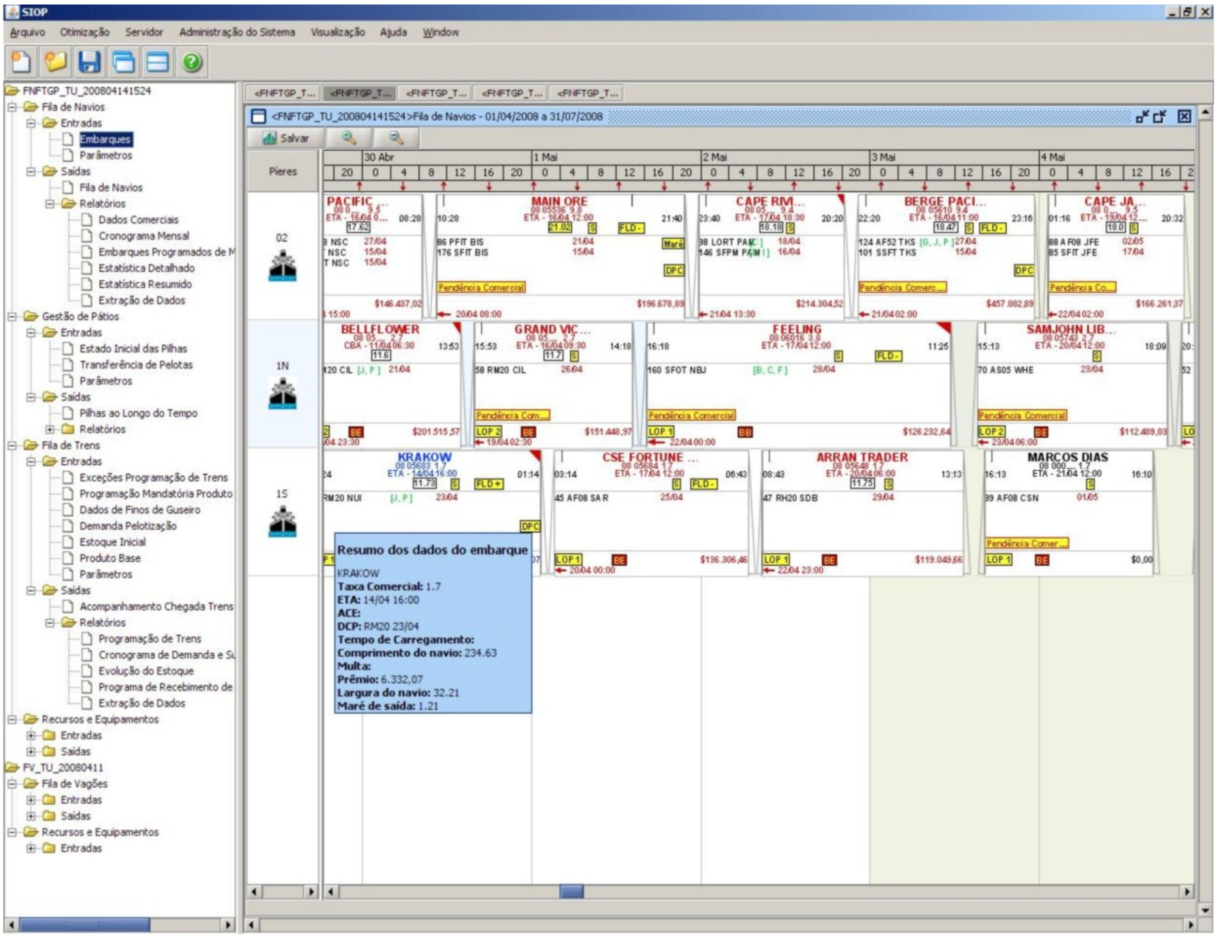

Figure 2: SIOP Vessel Queue view.

Figure 2 presents SIOP´s user interface opened with the Vessel Queue view. The window on the left shows the whole set of information that can be viewed. The box in dark blue indicates that shipment information is displayed in the main window on the right. In this window, each line represents a berth and the boxes contain the details of the shipments, while the placement and length of the box indicate the period that the associated ship is at the berth.

3.2 The Train Queue (TQ)

The decisions regarding the use of the trains available for each day is focused here. SIOP plans the use of this transportation capacity by considering for each type of iron ore, and for each final product, the limit for daily production and the minimum size a block of cars may have. Also, shipments ETB's and quantities, iron ore requirements from the pellet plants, together with train trips duration, trains sizes and time windows for arrival are taken into account.
Figure 3 presents SIOP's view for Train Queue planning. As above, the left window shows the information displayed in the main window, which here is the timeline of arrival of demands for iron ore. The right window presents a plan where each group of lines refers to a shipment. Grey boxes represent the lay days, blue ones are iron ore arrivals or iron ore in stock, the green boxes represent the DCP's of the shipments. Finally, the yellow and the red boxes are associated to the ETA and the

ETB, respectively. Note that the DCP boxes (green) coincide in time with the last iron ore arrival (blue).

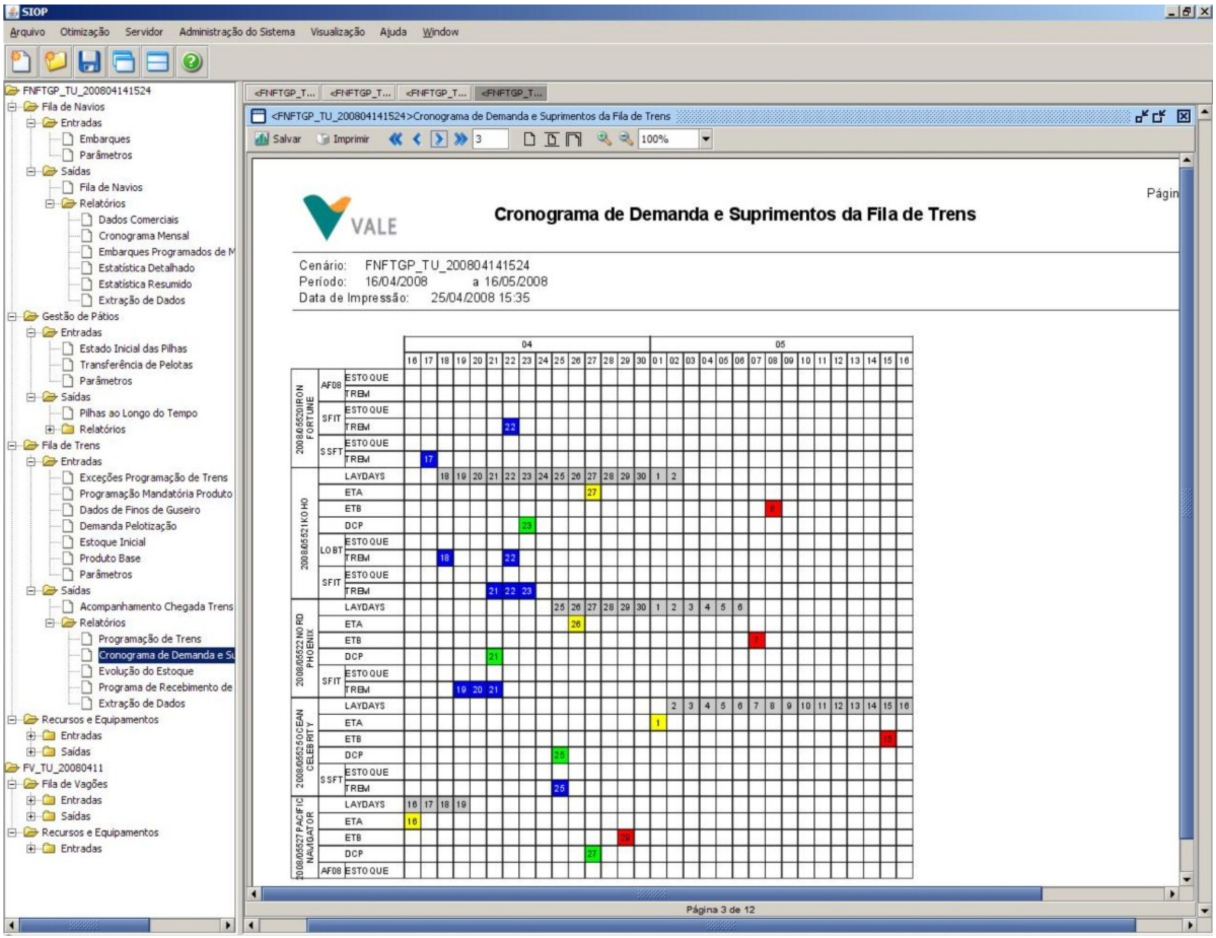

Figure 3: SIOP Train Queue view.

3.3 The Port Yard (PY)

The use of the port resources is the main concern of the managing decisions in this module. It deals with sizes of stockpiles and their variations due to the type of iron ore, as well as the priorities of use of the storage areas of the yard. These are linked with the available stackers and reclaimers that operate in each area, together with the routes the iron ore flows through the conveyor belts to form piles and to load the ships. All of this needs to be analyzed over time giving priority to activities already in course and to the ones already planed. Adjustments and new tasks must be incorporated to the plan in such a way that avoids disruptions as much as possible. Figure 4 shows SIOP´s view for the Port Yard management group. The right window is displaying the stockpiles at a given instant of time. Their changes along time can be seen by changing the date and hour at the top of the window. Each row represents a stock area, where all sectors are identified. The bottom left part of the window describes, for each shipment, the stockpiles used to load the associated vessel. The bottom right shows the stock of each product at the port areas.

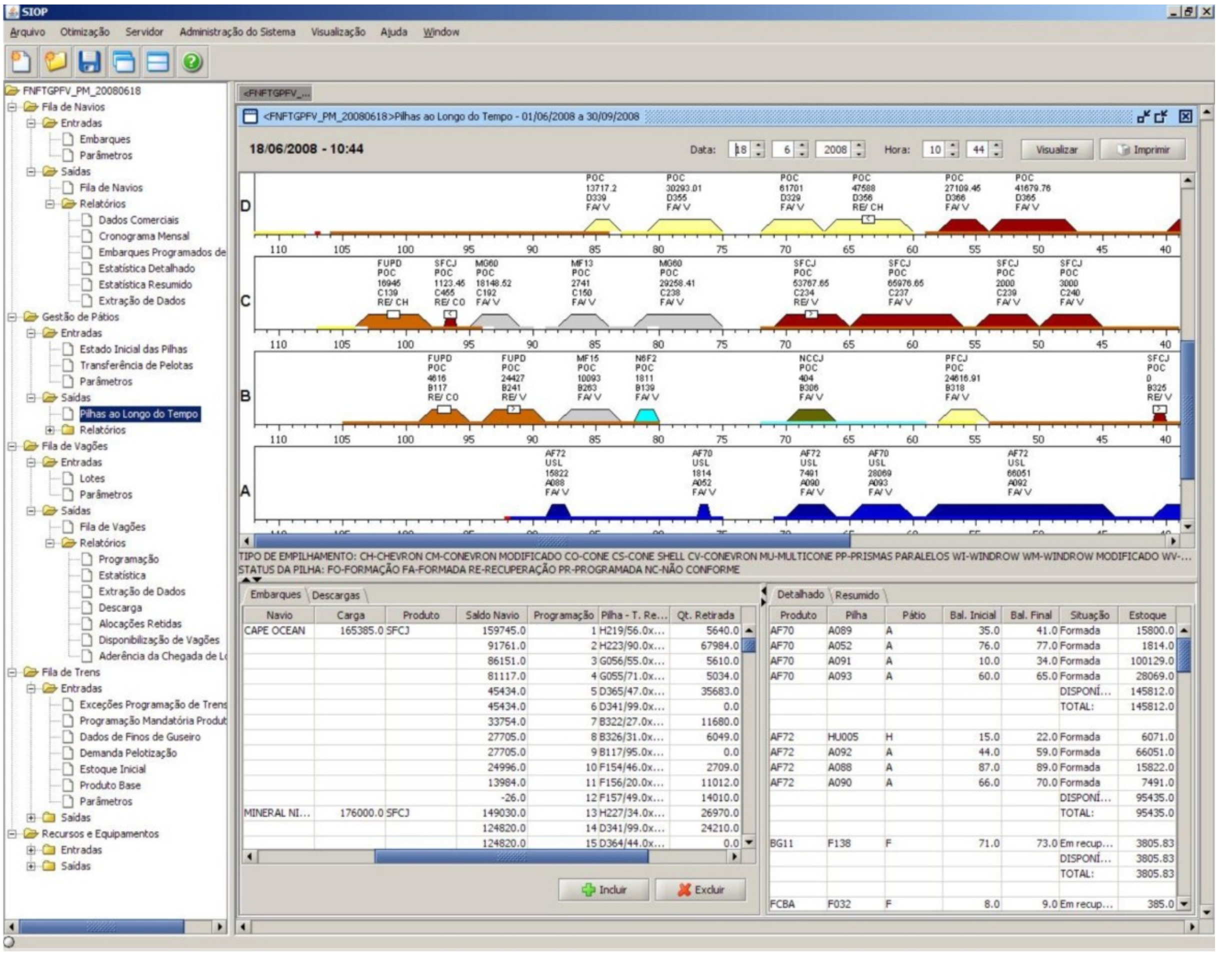

Figure 4: SIOP Port Yard view.

3.4 The Car Dumper (CD)

The trains arrive at the port continuously. At the arrival of a train, decisions related to the assignment of the blocks of wagons to the car dumpers must be taken. The main information for decision making includes the car blocks sizes (number of wagons) together with the types of iron ore they carry, the ETA of the shipment it meets and the placement of the stockpile. Devising this operations plan needs considering car dumpers and conveyor belt rates for the possible ways of moving the iron ore from the cars to the stock areas.

Figure 5 presents the car dumper view. Each line of the main window on the right represents a car dumper. The colored boxes are the unloading of a block of cars. The top of the window shows the date and the hours of the day the unloading is scheduled. Each box informs the number of cars, the product and the area sector associated to this the iron ore. The operator can graphically move the boxes in time and among car dumpers.

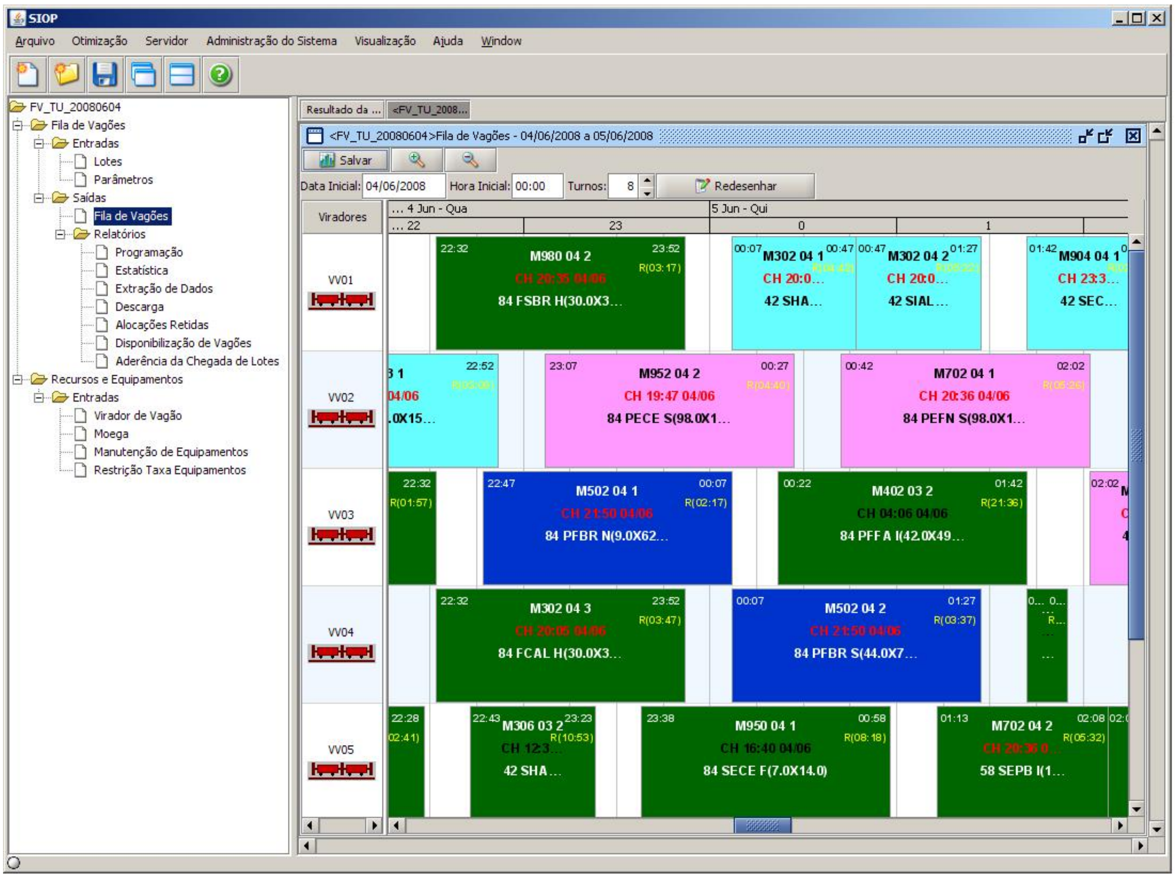

Figure 5: SIOP Car Dumper view.

3.5 The Operation Modes and Integrated Planning

SIOP provides seven modes of use to meet the managers' requirements. The first one is the "VQ mode" which plans the order the vessels will start being loaded at each berth by assuming it is possible to have the DCP's for the corresponding shipments before the vessel is berthed and, of course, all the information related to the port described above. This corresponds to the isolated planning done by the VQ group.

The second mode, the "VQ fixed + TQ", considers that an operation plan defined by the VQ group cannot be changed and assumes the car dumper and port yard will not be a bottleneck for the trains arrival and the proper stock arrangement and ship loading. This mode will then provide a TQ plan that meet the VQ plan or indicate it is not possible to do this. It is used for the isolated planning of the TQ group.

The third mode is the "integrated VQ + TQ". It assumes the previous no bottleneck conditions. It provides the managers in the VQ and the TQ groups with a tool that generates a joint operation plan. This is the first level of integrated planning.

The fourth mode of SIOP is the "VQ fixed + TQ fixed + PY mode". It allows the managers to test whether an operation plan for the ship berthing and loading of the trains can be executed with the current port yard resources and, in the positive case, provides a yard operation plan. In other words, the PY group plans on its own in this mode.

The fifth mode allows devising a plan for these three management activities. The "integrated VQ + TQ + PY mode" assumes the car dumper will not be a bottleneck for the port operation and generates a plan that considers the particularities of the

decisions that fall under the responsibility of these three groups. It configures the second level of integration.
The sixth mode discards the previous assumption that the port yard and card dumper will not configure a bottleneck. It generates a complete plan for the port operation. This “integrated VQ + TQ + PY + CD mode" aims at providing a common ground for negotiation among the managing groups, being a tool to evaluate the volume limits the productive system can handle. This corresponds to the completely integrated mode.
Finally, there is the "CD mode", the seventh mode. It supports the online decision of which block of train cars will be processed by which car dumper, in order to allow a swift stock pile formation and ship loading operation. It configures the isolated planning of the CD group. All the seven modes have specialized algorithms capable of providing fast solutions and to evaluate their quality. The next section describes the main concepts behind these algorithms.

4 THE DECISION ALGORITHMS AND INTEGRATED OPTIMIZED PLANNING

In this section we give a description of the concepts and ideas behind the algorithms present in SIOP’s operation modes. We recall that the main objective of the productive systems, and consequently, of SIOP’s algorithms, is maximizing the throughput, i.e. the total volume of iron ore that is shipped. The four isolated modes correspond already to very detailed and constrained problems. The operations plan that they generate has to follow a long list of rules. Besides, the amount of data is considerably large, which demands from the algorithms smart ways for considering the entire information set.
The main concept behind all the algorithms is the establishment of priorities for the assignment of resources to entities, which may be ships, blocks of cars or amounts of iron ore. This allows determining in a fast way how tight, in terms of generating a valid plan, is the planning problem. Besides the priorities, a few operation rules, such as spacing in time the dumping of blocks of cars with same areas as destination for the iron ore, are followed. The next step is a limited enumeration of all possible planning decisions, which is done by continuously testing the expected maximum throughput subjected to decisions taken before in the algorithm.
This approach allows, for instance, detecting that the tides justify a change in the order of berthing given by the FIFO arrival rule. A large ship that arrived first may get stuck at a berth due to the tide. A smaller ship may then use the same berth and complete its loading without change the departure date of the larger ship. Similar behavior can be observed in all these four modes.
The challenge to generate optimized valid plans efficiently becomes a greater one when integration is an important issue. Moreover, the response time must be kept as short as possible, since the four independent modes execute in a few minutes. To meet this objective, a main key was to follow the steps of the decision process in use among the management groups. Let’s consider first the "integrated VQ + TQ" (Figure 6). There are only a few parameters that derive from the two individual planning
that must agree in an integrated plan. In the case of this mode, they are the estimated time of berthing (ETB) and departure (ETD) and the DCP, date the shipment stockpiles must be completed. The ETA is the initial information for planning.

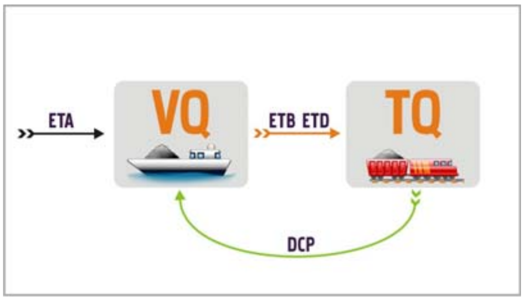

Figure 6: Integration of Vessel Queue and Train Queue.

The steps followed by the algorithm for this integrated optimization are: devise an operations plan for the VQ, this generates values for all the ETB's and ETD's; with those values determined the TQ can calculate the DCP; it is then tested whether the DCP value is valid for the values for the ETB's and ETD's, if it is and integrate plan was obtained. Otherwise, these steps are repeated with appropriated modifications.

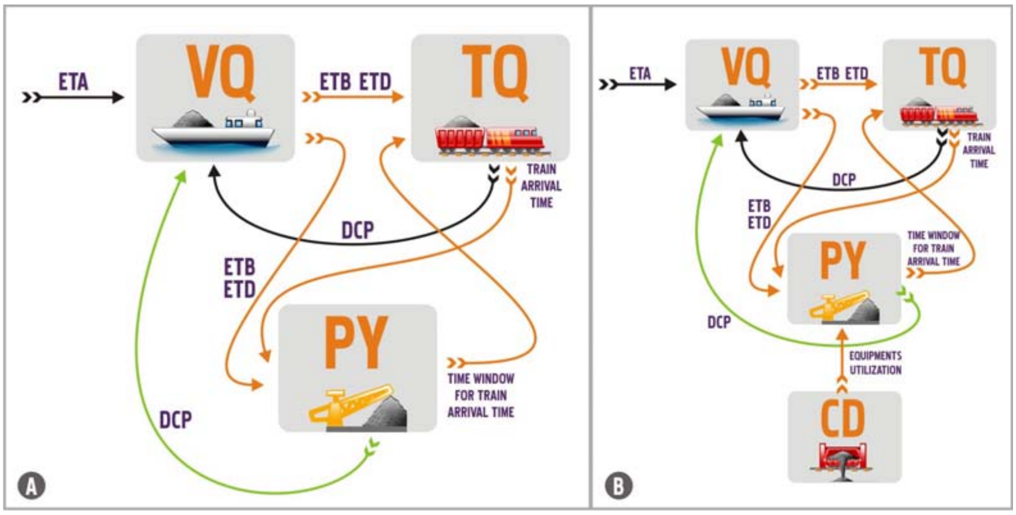

Figure 7: Integrated Modes "VQ+PY+TQ" (a) and "VQ+PY+TQ+CD" (b)

The second level of integration aggregates the PY to the vessel and train queue resulting in the "integrated VQ + TQ + PY mode". This brings the information on the train arrival time to play. Since the ETB gives to the yard management group a date on which the shipment must be ready for loading, the train arrival time will tell the periods where each shipment iron ore should be traveling from the car dumpers to the stock piles. Forming piles and loading ships may turn out to be activities blocking each other, delaying ETD's and consequently reducing the overall productivity. This shows that avoiding blocking, one of the main objectives of SIOP, requires integrated planning and optimization (Figure 7 (a)).

An approach similar to the first level is used. Once a valid integrate solution is obtained to the VQ and the TQ, ETB's, ETD's and train arrival times are available to proceed to the PY and generate a yard plan. A new DCP and time windows for train arrivals are calculated by the PY. The test whether the VQ+TQ plan copes with the new DCP's and train time windows indicates if a valid integrated plan was obtained or, else, if a new VQ+TQ plan must be generated with appropriate new requirements. These steps are repeated until an integrated valid plan is obtained.

The integration of the CD mode is done in a simpler way. Since the CD operations have a short planning horizon and decisions are taken upon arrival of trains, it has a higher priority. As a result, SIOP obtains a completely integrated planning by following the steps above to compute the VQ+PY+TQ integrated planning with the additional restrictions imposed by the CD planning. Figure 6 (b) depicts this completely integrate planning.

5 DISCUSSION

The development of SIOP involved a period of more than six months of specifications and understanding how the system should operate and support the decisions of the managing groups, both individually and integrated. The conception phase of SIOP involved managers of the three productive systems of VALE and from the development companies GAPSO and Ci&T. Experts on all the port operations from all the productive systems gave opinions and made significant contributions to the design of the final system. The challenge of putting in production an integrated optimization system for all the port operations at VALE was overcome in roughly two years. Although the objectives of SIOP were very well defined in the beginning of its development, it is undeniable the contributions of all the participants not only in the way it functions and interfaces with the users operations, but also in all its algorithms within.

Until now, only a few months after SIOP being fully operational in all three productive systems, results can only be measured in terms of the efficiency and the agility of the planning and the operation at the ports. Managers are now able to react faster to changes. Decisions upon accepting or not unexpected shipments can now be taken more wisely. Recovery plans for equipments breaks can be devised with the support of SIOP. Above all, managers have time now to double-check all the operations decisions and to dedicate to higher level questions regarding the operations.

Nevertheless, quantitative results will only be able to be measured, in the future, in terms of the aggregated port production. This is due to the wide range of contributions this planning system offers. The information organization, the operations global visualization and the automated planning, each one bring new possibilities to the managers decision making. Quantitative results will then be the consequence of this joint work.

6 CONCLUSIONS

SIOP users can quickly plan and visualize their operations and the use of their resources. The seven modes of SIOP allow generating optimized, integrated or local (within the scope of one managing group), planning. This activity used to take four to six hours, now it can be done in a few minutes. As a result, the managing groups have now time to analyze several scenarios and use their expertise to design a more robust and improved operations plan. Moreover, this agility is mandatory to provide proper answers regarding accepting or not new shipments. All this amounts to having a more aware and swift iron ore logistic with the use of an integrated optimized planning system.