UM SISTEMA PARA OTIMIZAR O PLANEJAMENTO DA PRODUÇÃO E VENDAS DE UMA EMPRESA MINERADORA

OPTIMIZATION OF THE PRODUCTION AND SALE PLANNING OF A MINING COMPANY

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Abstract

This work deals with the production and sale planning of a Brazilian company of the mineral extractive sector. In this problem, iron ore from several Ore Treatment Installations, so-called Primary Products, are blended to produce the sale products, so-called Final Products. The decisions are taken in trimesters and the planning horizon is one year. A model based on goal programming is proposed. This mathematical model was implemented in LINGO 10.0 and used in a system developed in Visual Basic for Applications language inside Microsoft Excel XP. Computational results show that the system is able to produce optimal solutions quickly, allowing the analysis of several sceneries before decision.

KEYWORDS: *Production Planning, Goal Programming, Ore Blending.*

Resumo

Este trabalho trata do Problema de Planejamento da Produção e Vendas de uma empresa brasileira do setor extrativo mineral. Neste problema, minérios provenientes de diversas Instalações de Tratamento de Minérios, chamados de Produtos Primários, são blendados com o objetivo de comporem os produtos de venda, chamados de Produtos Finais. As decisões são tomadas por trimestres em um horizonte de planejamento de um ano. É proposto um modelo baseado na programação linear por metas para sua resolução. Esse modelo foi implementado no modelador e otimizador LINGO 10.0 e embutido em um sistema desenvolvido na linguagem Visual Basic for Applications do Microsoft Excel XP. Resultados computacionais mostram que o sistema desenvolvido é capaz de gerar soluções ótimas rapidamente, possibilitando ao usuário analisar vários cenários antes da tomada de decisão.

Palavras-chave: Planejamento da Produção, Programação Linear por Metas, Blendagem de Minérios.

1. Introduction

The mining production and sales planning (MPSP) consists of a medium-term plan, usually lasting twelve months, and its purpose is to determine the amount and place in which each iron ore and when this ore, which comes from different Iron Ore Treatment Plants (IOTPs), should be used to create the company's products that will be sold. Each iron ore from these plants has different physical and chemical characteristics, such as the content of a certain chemical component or the granulometric analysis. Thus, each kind of iron ore contributes with a certain appropriate feature so that the Final Product is as close to the client's demands as possible.

According to Pimentel et al. (2010) and Almeida and Pimentel (2009), problems in the mining business have been widely solved through operations research techniques; however, these problems are usually subdivided into smaller and interdependent problems in order to be solved. Therefore, there is no assurance that the combination of the best solution for the sub-problems will end up in the optimum global solution. The MPSP, for instance, is usually divided in independent quarterly events. For each quarter, the problem is solved respecting the production capacity of the Iron Ore Treatment Plants (IOTPs) and railway stations. The disadvantage of this procedure is that when the sub-problems are solved, the demands of the following quarters are not taken into account. Thus, it may not be possible to meet the demands of a following quarter in regards to quality since the products needed may have already been used in a previous quarter. On the other hand, many existing models in literature do not accurately depict real situations since they ignore several operational restrictions. However, according to Ruiz et al. (2008), there is an increasing tendency to develop models that take real cases in the industry into consideration.

In this matter, this study contributes to the creation of an integrated linear programming model based on goals to support medium term tactical decisions on mining production and sales planning of a mining company.

2. Problem Description

The problem addressed refers to an iron ore mining company located in the *Quadrilátero Ferrífero* region, in the state of Minas Gerais, Brazil. This company has several Operational Units (OUs). Each OU contains one or more Iron Ore Treatment Plants (IOTPs). The IOTP are responsible to enrich and make available the various types of iron ore mined. The ores processed by the IOTPs have different characteristics and are called primary products.

The products generated by the mining company are transported by highways directly to domestic clients or transferred to the Loading Terminals, from which they go by rail to two possible destinations: the domestic market or the marine terminals responsible for exporting the supply to foreign clients. The customers require iron ore with certain characteristics or quality specifications. These specifications are called Final Products.

In order to compose the Final Products, it is necessary to blend several Primary Products to obtain an iron ore that meets the quality specifications required by the clients. Therefore the MPSP consists in determining, for each planning period, the amount of Primary Products to be blended to compose the Final Products, respecting the operational restrictions of the company. Figure 1 shows the production process of a mining company. This process starts in the ore mining, where the ore is extracted, then it is enriched at the IOTPs to become a Primary Product. Finally, the Primary Products are transported to the clients, being mixed on the way to become the Final Products.

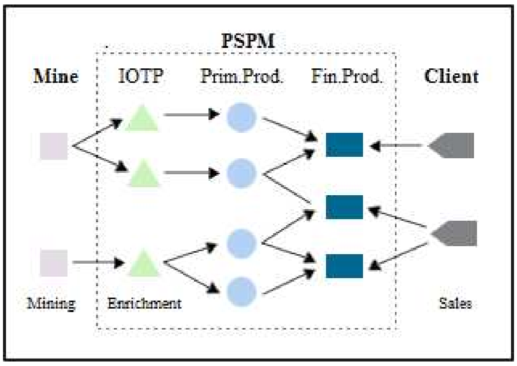

Figure 1 – Production process of a mining company

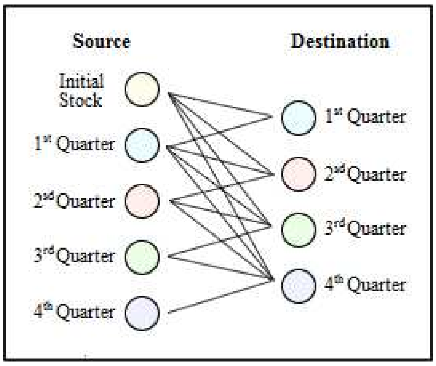

Figure 2 – Stock logistics for MPSP

Iron ores are classified in families according to their characteristics, which are called control parameters. These parameters are divided into chemicals (iron, silica, manganese, phosphorus, etc.) and physical (humidity and granulometric range). There are four major families of ores: LO (Lump Ore) and HEM (Hematite), granulated materials with granulometric range above 6mm and SF (Sinter Feed), PFF (Pellet Feed), which are materials with granulometric range below 6mm.

During the handling of the products, some oscillations occur in the iron ore characteristics that must be taken into consideration for the MPSP. Such distortions are corrected by applying Handling Factors that determine the variations of each one of the control parameters for various situations. There are two basically two Handling Factors: (*i*) Mine-Train – which is applied to Primary Products transported by rail and (*ii*) Train Port – which is applied to Final Products transported by ship.

The MPSP imposes blending restrictions that must be respected so that Primary Products from different families are not mixed up. Therefore, the mining company determines the blending possibilities. In other words, it pre-determines which products may be blended to make a specific Final Product, as shown in table 1.

Table 1 – Blending possibilities for some Final Products:

Final Product	Blending Possibilities (Primary Products)
LO	LO (OU1, IOTP A), LO (OU 2, IOTP B)
SF	SF (OU1, IOTP A), SF (OU2, IOTP B), SF (OU3, IOTP C), SF (OU4, IOTP D), SF (OU4, IOTP E), SF (OU4, IOTP F), SF (OU5, IOTP F), SF (OU5, IOTP G)

Table 1 shows that the Final Product LO may be made up of iron ore coming from IOTP A of Operational Unit 1, only by iron ore from IOTP B of operational unit 2 or by blending both.

There are other operational restrictions from the mining company that must be taken into consideration like: IOTP's production capacity, the loading capacity in the Loading Terminals and whether a Final Product will be transported by rail or road.

Finally, it must be pointed out that the MPSP problem considered in this article refers to the planning of one year divided in quarters. Therefore, the production of Primary Products, as well as the demand for Final Products, is distributed over time in quarters. Thus, it is possible that the demand in one quarter is fulfilled by the production of previous quarters, as shown by Figure 2. For instance, Primary Products produced in the first quarter of a year may be used to meet the demand of all quarters concerning a specific Final Product.

3. Modeling of the Problem

In this section, a mathematical model based on goal programming (ROMERO, 2004) is proposed in order to optimize the MPSP. The goal is to make a better use of the company's resources.

3.1. Entry Parameters

$prodpri$	group of Primary Products from ITM's;
$prodfin$	group of Final Products to be sold;
S	group of quality parameters analyzed in the Final Products;
TC	group of Loading Terminals;
$DispEst_i$	amount of Primary Product *i* (in tons) available in the initial stock;
$EliQtd_i$	amount of Primary Product *i* that must be eliminated (in tons);
$EliPro_i$	assumes the value 1 if a value is defined for $EliQtd_i$ and 0 otherwise;
$PosBld_{ij}$	assumes the value 1 if the Primary Product *i* can be blended to create the Final Product *j* and 0 otherwise;
$DBldEst_{ijl}$	amount of iron ore (in tons) available in the initial stock of Primary Product *i* that must be blended in the Final Product *j* in quarter *l*;
$DBldPro_{ijlm}$	amount of iron ore (in tons) produced in quarter m of the Primary Product *i* that must be blended in the Final Product *j* in quarter *l*;
$TEst_{ik}$	percentage of parameter *k* in the Primary Product *i* available in the initial stock;
$TEstFM_{ik}$	percentage of parameter *k* in the Primary Product *i* available in the initial stock. The Mine-Train handling factor is applied;
$TPro_{ikm}$	percentage of the parameter *k* in the Primary Product *i* produced in quarter *m*;
$TProFM_{ikm}$	percentage of the parameter *k* in the Primary Product *i* produced in quarter *m*. The Mine-Train handling factor is applied;
$DispPro_{im}$	the production capacity (in tons) of the Primary Product *i* in quarter *m*;
$TCTip_i$	the train Loading Station that loads Primary Product *i*;
$TrpFer_j$	assumes the value 1 if the Final Product *j* is transported by rail and 0 otherwise;
wdd_j	weight in the objective function if the demand of Final Product *j* is not satisfied;

Dem_{jl}	demand in tons of Final Product *j* in quarter *l*;
wdt_{jk}	weight in the objective function in case of not meeting the content of parameter *k* in the Final Product *j*;
$TeorTT_{jkl}$	desired goal of typical content of parameter *k* for Final Product *j* in quarter *l*;
$TeorLI_{jk}$	lower bound of parameter *k* for Final Product *j*;
$TeorLS_{jk}$	upper bound of parameter *k* for Final Product *j*;
$DTBlqT_{jkl}$	assumes the value 1 if the goal restriction in quarter *l* regarding parameter *k* in Final Product *j* must be fully satisfied and 0 otherwise;
$TCCap_t$	the loading capacity of the train loading station *t*;

3.2. Decision Variables

$XEst_{ijl}$	the amount (in tons) of iron ore available in the initial stock of Primary Product *i* that will be blended to create Final Product *j* in quarter *l*;
$XProd_{ijlm}$	the amount (in tons) of iron ore produced of Primary Product *I* in quarter m that will be blended to create Final Product *j* in quarter *l*;
Dtp_{jkl}	positive deviation from the goal of parameter *k* in the Final Product *j* in quarter *l*;
Dtn_{jkl}	negative deviation from the goal of parameter *k* in the Final Product *j* in quarter *l*;
Dlp_{jkl}	positive deviation from the upper bound of parameter *k* in the Final Product *j* in quarter *l*;
Dln_{jkl}	negative deviation from the lower bound of parameter *k* in the Final Product *j* in quarter *l*;
$DDem_{jl}$	unsatisfied demand of Final Product *j* in quarter *l*;

3.3. Mathematical Model

The objective function (3.1) contains two parts. The first one aims to minimize quality deviations and the second one aims to minimize unsatisfied demands. Equations (3.2) and (3.3) measure how much the upper and lower bounds of quality have not been achieved, respectively. Equations (3.4) measure the quarter's goal deviations from the control parameters. When the control parameters constraints must be satisfied ($DTBlqT_{jkl} = 1$), equations (3.4) are substituted by equations (3.5), forcing the company to reach the quality goals. Equations (3.10) and (3.11) guarantee that Primary Products are not blended to create Final Products when they are inadequate for blending ($PosBld_{ij} = 0$) and an obligatory blending has not been defined ($DBldEst_{ijl} = 0$ and $DBldPro_{ijlm} = 0$). Equations (3.12) do not let the Loading Limits of the train loading stations get exceeded. The Restrictions (3.13) and (3.14) force the blending to be achieved when defined by the user of the system ($DBldEst_{ijl} \neq$ de 0 or $DBldPro_{ijlm} \neq$ de 0). Finally, equations (3.15) force that $EliQtd_i$ of the Primary Product *i* is used when imposed by the user ($EliPro_i = 1$).

$$\min \sum_{l=1}^{4}\sum_{k\in S}\sum_{j\in ProdFin}\left[wdt_{kj}\left(Dtp_{jkl}+Dtn_{jkl}+Dlp_{jkl}+Dln_{jkl}\right)\right] + \sum_{j\in ProdFin}\left(wdd_j \times DDem_j\right) \tag{3.1}$$

$$\sum_{\substack{i\in ProdPri \\ \mid PosBld_{ij}=1\ \&\ TrpFer_j=0}} \left\{ \sum_{\substack{m=1 \\ m\le l}}^{4}\left(TPro_{ikm}\times XProd_{ijlm}\right) + TEst_{ik} XEst_{ijl} \right\} + \sum_{\substack{i\in ProdPri \\ \mid PosBld_{ij}=1\ \&\ TrpFer_j=1}} \left\{ \sum_{\substack{m=1 \\ m\le l}}^{4}\left(TProFM_{ikm}\times XProd_{ijlm}\right) + TEstFM_{ik}\times XEst_{ijl} \right\} - Dlp_{jkl} \le TeorLS_{jk} \quad \forall\, j\in ProdFin,\ \forall\, k\in S,\ \forall\, l=1..4,\ \mid TeorLS \neq 0 \tag{3.2}$$

$$\sum_{\substack{i\in ProdPri \\ \mid PosBld_{ij}=1 \,\&\, TrpFer_j=0}} \left\{ \sum_{\substack{m=1 \\ m\le l}}^{4} \left(TPro_{ikm} \times XProd_{ijlm}\right) + TEst_{ik}\times XEst_{ijl} \right\} + \sum_{\substack{i\in ProdPri \\ \mid PosBld_{ij}=1 \,\&\, TrpFer_j=1}} \left\{ \sum_{\substack{m=1 \\ m\le l}}^{4} \left(TProFM_{ikm}\times XProd_{ijlm}\right) + TEstFM_{ik}\times XEst_{ijl}\right\} + Dln_{jkl} \ge TeorLI_{jk} \qquad \forall\, j\in ProdFin,\ \forall\, k\in S,\ \forall\, l=1..4,\ \mid TeorLI \ne 0 \qquad (3.3)$$

$$\sum_{\substack{i\in ProdPri \\ \mid PosBld_{ij}=1 \,\&\, TrpFer_j=0}} \left\{ \sum_{\substack{m=1 \\ m\le l}}^{4} \left(TPro_{ikm} \times XProd_{ijlm}\right) + TEst_{ik}\times XEst_{ijl} \right\} + \sum_{\substack{i\in ProdPri \\ \mid PosBld_{ij}=1 \,\&\, TrpFer_j=1}} \left\{ \sum_{\substack{m=1 \\ m\le l}}^{4} \left(TProFM_{ikm}\times XProd_{ijlm}\right) + TEstFM_{ik}\times XEst_{ijl}\right\} - Dtp_{jkl} + Dtn_{jkl} = TeorTT_{jkl} \qquad \forall\, j\in ProdFin,\ \forall\, k\in S,\ \forall\, l=1..4,\ \mid TeorTT \ne 0 \,\&\, DTBlqT_{jkl}=0 \qquad (3.4)$$

$$\sum_{\substack{i\in ProdPri \\ \mid PosBld_{ij}=1 \,\&\, TrpFer_j=0}} \left\{ \sum_{\substack{m=1 \\ m\le l}}^{4} \left(TPro_{ikm} \times XProd_{ijlm}\right) + TEst_{ik}\times XEst_{ijl} \right\} + \sum_{\substack{i\in ProdPri \\ \mid PosBld_{ij}=1 \,\&\, TrpFer_j=1}} \left\{ \sum_{\substack{m=1 \\ m\le l}}^{4} \left(TProFM_{ikm}\times XProd_{ijlm}\right) + TEstFM_{ik}\times XEst_{ijl}\right\} = TeorTT_{jkl} \qquad \forall\, j\in ProdFin,\ \forall\, k\in S,\ \forall\, l=1..4,\ \mid TeorTT \ne 0 \,\&\, DTBlqT_{jkl}=1 \qquad (3.5)$$

$$\sum_{i\in ProdPri} \sum_{\substack{m=1 \\ \mid m\le l \\ PosBld_{ij}=1}}^{4} \left(XProd_{ijlm} + XEst_{ijl}\right) + DDem_{jl} = Dem_{jl} \qquad \forall\, j\in ProdFin,\ \forall\, l=1...4 \qquad (3.7)$$

$$\sum_{j\in ProdFin} \sum_{\substack{m=1 \\ \mid m\le l \,\& \\ PosBld_{ij}=1}}^{4} \left(XProd_{ijlm}\right) \le DispPro_{im} \qquad \forall\, i\in ProdPri,\ \forall\, m=1...4 \qquad (3.8)$$

$$\sum_{j\in ProdFin} \sum_{\substack{l=1 \\ \mid PosBld_{ij}=1}}^{4} \left(XEst_{ijl}\right) \le DispEst_i \qquad \forall\, i\in ProdPri \qquad (3.9)$$

$$XProd_{ijlm} = 0 \qquad \forall\, i\in ProdPri,\ \forall\, j\in ProdFin,\ \forall\, l=1...4,\ \forall\, m=1...4 \mid PosBld_{ij}=0 \,\&\, DBlPro_{ijlm}=0 \qquad (3.10)$$

$$XEst_{ijl} = 0 \qquad \forall\, i\in ProdPri,\ \forall\, j\in ProdFin,\ \forall\, l=1...4 \mid PosBld_{ij}=0 \,\&\, DBlEst_{ijl}=0 \qquad (3.11)$$

$$\sum_{\substack{i\in ProdPri \\ \mid TCTip_i=t}} \sum_{\substack{j\in ProdFin \\ \mid TrpFer_j=1}} \sum_{\substack{m=1 \\ \mid m\le l \\ PosBlend=1}}^{4} \left(XProd_{ijlm} + XEst_{ijl}\right) \le TCCap_t \qquad \forall\, l=1...4,\ \forall\, t\in TC \qquad (3.12)$$

$$XProd_{ijlm} = DBldPro_{ijlm} \qquad \forall\, i\in ProdPri,\ \forall\, j\in ProdFin,\ \forall\, l=1..4,\ \forall\, m=1..4,\ m\le l \mid DBldPro_{ijlm}\ne 0 \qquad (3.13)$$

$$XEst_{ijl} = DBldEst_{ijl} \qquad \forall\, i\in ProdPri,\ \forall\, j\in ProdFin,\ \forall\, l=1..4,\ m\le l \mid DBldEst_{ijl}\ne 0 \qquad (3.14)$$

$$\sum_{j\in ProdFin} \sum_{l=1}^{4} \sum_{\substack{m=1 \\ \mid m\le l \,\& \\ PosBld_{ij}=1}}^{4} \left(XProd_{ijlm}\right) + \sum_{j\in ProdFin} \sum_{\substack{l=1 \\ \mid PosBld_{ij}=1}}^{4} \left(XEst_{ijl}\right) \ge EliQtd_i \qquad \forall\, i\in ProdPri \mid EliQtd_i \ne 0. \qquad (3.15)$$

4. Results

The mathematical model was implemented in Lingo 10.0 (Lindo Systems) optimizer. A system to use and run the model was developed in Microsoft Excel Visual Basic for Applications (VBA).

A common planning problem in the company, which involved 74 Primary products, 50 Final Products, 8 loading terminals, 10 Operational Units and 21 Iron Ore Treatment Plants (IOTPs) was used to test the system, which was extensible tested by the company engineers. In an annual planning of four quarters, such problem is solved by the system in less than 15 seconds by an AMD Athlon (tm) 3200 2.00GHz computer with 480 MB of RAM memory. Before the system was developed, the engineers used to take at least one week to obtain a feasible plan.

As previous data was not available for analysis, so unfortunately it was not possible to compare the solutions used by the company in previous years to the ones obtained by the developed system. Therefore, some of the Primary Products and Final Products belonging to the problem previously mentioned are presented next, as well as part of the solution found by the system. The idea is to make clearer the understanding of the mining production and sales planning (MPSP).

Table 2 shows entry data that refers to Final Product 'PFin4' and 'PFin24': demands for each one of the quarters, the market which it belongs to (export or domestic), weight for satisfying the demands, the product specification established to be met and its standard deviation (SD), weight for each of the control parameters and, finally, the train-port handling factors. The weight for the control parameters used has the following meanings, by descending order of importance: Very Critical (VC), Critical (CR), Very Important (VI), Important (IM), Less Important (LI) and Irrelevant (IR). As for the amplitude deviation, 1/2 of an SD, 1 of an SD and 4 of an SD represent the distance between the goal and limits of quality. For instance, product 'PFin24' has a 67,00% goal for "Fe", an SD of 0.25% and an amplitude deviation of a 2 SD , means that the content of iron can vary between 66.50% and 67.50%.

Table 2 – Entry data of Final Products 'PFin4' and 'PFin24':

Market	Final Product	Demands (Kt)				Demand Weight
		1º Quarter	2º Quarter	3º Quarter	4º Quarter	
Export	PFin4	307	450	450	343	MC
Domestic	PFin24	40	160	200	120	MC

Market	Final Product	Specification - Goal / Standard Deviation (%)															
		Fe		SiO_2		Al_2O_3		P		Mn		H_2O		OS		US	
Export	PFin4	66,28	0,20	1,45	0,12	1,45	0,15	0,055	0,006	0,290	0,060	3,0	0,4	6,0	2,5	20,0	5,0
Domestic	PFin24	67,00	0,25	1,65	0,15	1,10	0,13	0,115	0,015	0,075	0,025	3,5	0,4	10,0	2,5	7,0	1,0

Market	Final Product	Weights / Deviation															
		Fe		SiO_2		Al_2O_3		P		Mn		H_2O		OS		US	
Export	PFin4	MI	2dp	MI	2dp	CR	2dp	MI	2dp	MI	2dp	IR	2dp	MI	2dp	MI	2dp
Domestic	PFin24	IR	2dp	IR	2dp	IR	2dp	IR	2dp	IR	2dp	IR	2dp	IR	2dp	IR	2dp

Market	Final Product	Handling Factor Train-Port (%)							
		Fe	SiO_2	Al_2O_3	P	Mn	H_2O	OS	US
Export	PFin4								
Domestic	PFin24	0,10	-0,02	0,07	-0,009	-0,010	-0,3	-5,0	-0,5

Table 3 specifies part of the data for some of the Primary Products. The table shows the Operational Unit (Oper. Unit), the IOTP where the product is produced, the Loading Station (Load. Ter.) where the product is dispatched, the quantity of product (Qt.), in kilotons, and its quality specification in relation to the initial stock (Percentages – Initial Stock), as well as the blending possibilities. The two last columns (Blending Possibilities) assume values 1 or 0 respectively, hatched or not. When the cell is hatched, it means that the Primary Product of that respective line may be used to compose the Final Product. Thus, for example, 'PFin4' can be made up of Primary Products 'PPri30', PPri32', 'PPri36', 'PPri39', 'PPri41','PPri45','PPri47' and 'PPri49'. The entry data related to the Mine-Train handling Factors have been omitted, as well as the quantity and quality of the quarter's Primary Products.

Table 3 – Part of the entry data for the Primary Products:

Oper. Unit	IOTP	Primary Product	Loading Terminal	Qt. (Kt)	Percentages - Initial Stock (%)								Blending Possib.	
					Fe	SiO2	Al2O3	P	Mn	H2O	OS	US	PFin4	PFin24
OU5	ITM10	PPri30	TC4										1	0
		PPri31	TC4										0	0
OU6	ITM11	PPri32	TC3										1	1
		PPri33	TC3										0	0
		PPri34	TC3										0	0
		PPri35	TC3										0	0
OU7	ITM12	PPri36	TC2	893	63,22	2,40	2,31	0,105	0,777	4,5	13,1	13,1	1	0
		PPri37	TC2	405	63,60	2,55	1,97	0,099	0,863	4,3	21,2	12,7	0	0
		PPri38	TC2										0	0
	ITM13	PPri39	TC2										1	0
		PPri40	TC2										0	0

OU8	ITM16	PPri41	TC2	797	65,10	0,77	3,00	0,052	0,524	3,4	8,5	3,5	1	0
		PPri42	TC2	231	64,41	1,60	2,42	0,068	0,493	5,8	9,4	14,9	0	0
		PPri43	TC2										0	0
		PPri44	TC2										0	0
OU9	ITM18	PPri45	TC8	1037	65,68	1,65	1,60	0,064	0,222	4,1	18,8	2,5	1	0
		PPri46	TC8										0	0
	ITM19	PPri47	TC8	500	64,83	2,87	1,48	0,057	0,446	0,0	12,0	3,0	1	0
		PPri48	TC8	734	62,41	5,66	1,76	0,066	0,417	8,1	16,1	30,1	0	0
	ITM20	PPri49	TC8	168	67,34	1,28	0,87	0,048	0,112	4,1	18,8	2,5	1	0
		PPri50	TC8	407	66,52	1,51	1,20	0,051	0,201	5,1	0,0	11,4	0	0

Table 4 shows some blending configurations imposed by the engineer that must be taken into account by the mathematical programming model to solve the problem. The function “Impose Blending” demands that 30kt tons of ‘PPri30’, which was produced in the first quarter, is used to compose the Final Product ‘PFin4’ in the second quarter. The function “Meet Goal” determines that the percentage of control parameter “Fe” must be exactly 66.00%. In this case, the deviation must be equal to zero.

Table 4 – Blending Configuration

Impose Blending			
Period	**Primary Product**	**Final Product**	**Quantity**
1º Quarter -> 2º Quarter	PPri30 (OU5, ITM10)	PFin4	30 kt

Meet Goal			
Final Product	**Period**	**Parameter**	**Percentage**
PFin4	1º Quarter	Fe	66,00 %

Table 5 – Quarter’s composition of Final Product ‘PFin4’

1º Quarter – PFin4													
Operation Unit	**IOTP**	**Primary Product**	**Quant. (%)**	**Quant. (Kt)**	**Percentage (%)**								**Quarter Origin**
					Fe	**SiO_2**	**Al_2O_3**	**P**	**Mn**	**H_2O**	**OS**	**US**	
OU8	ITM16	PPri41	17,73	54	65,10	0,77	3,00	0,052	0,524	3,4	5,2	18,0	Stock
OU9	ITM19	PPri47	7,09	22	64,83	2,87	1,48	0,057	0,446	0,0	12,0	3,0	Stock
OU6	ITM11	PPri32	4,81	15	66,80	1,80	1,11	0,126	0,095	3,4	21,3	3,5	1º Quarter
OU7	ITM12	PPri36	18,16	56	63,42	2,10	2,12	0,114	0,498	4,5	21,0	6,5	1º Quarter
OU9	ITM20	PPri49	52,21	160	67,29	1,23	0,85	0,046	0,135	3,4	8,4	15,7	1º Quarter
Availability				307	66,00	1,45	1,52	0,064	0,290	3,3	11,0	12,9	-
Demand				307	66,28	1,45	1,45	0,055	0,290	3,0	6,0	20,0	-

2º Quarter – PFin4													
Operation Unit	**IOTP**	**Primary Product**	**Quant. (%)**	**Quant. (%)**	**Percentage (%)**								**Quarter Origin**
					Fe	**SiO_2**	**Al_2O_3**	**P**	**Mn**	**H_2O**	**OS**	**US**	
OU8	ITM16	PPri41	31,80	143	65,10	0,77	3,00	0,052	0,524	3,4	5,2	18,0	Stock
OU5	ITM10	PPri30	6,67	30	65,83	2,21	1,73	0,050	0,388	4,0	9,0	3,0	1º Quarter
OU5	ITM10	PPri30	16,53	74	65,84	2,37	1,72	0,046	0,287	4,0	9,0	3,0	2º Quarter
OU6	ITM11	PPri32	26,91	121	66,89	1,73	0,96	0,132	0,051	3,4	21,3	3,5	2º Quarter
OU9	ITM20	PPri49	18,09	81	67,40	1,11	0,76	0,048	0,167	3,4	8,4	15,7	2º Quarter
Availability				450	66,17	1,45	1,75	0,072	0,284	3,5	11,0	10,2	-
Demand				450	66,28	1,45	1,45	0,055	0,290	3,0	6,0	20,0	-

3º Quarter – PFin4													
Operation Unit	**IOTP**	**Primary Product**	**Quant. (%)**	**Quant. (%)**	**Percentage (%)**								**Quarter Origin**
					Fe	**SiO_2**	**Al_2O_3**	**P**	**Mn**	**H_2O**	**OS**	**US**	
OU7	ITM12	PPri36	8,69	39	63,22	2,40	2,31	0,105	0,777	4,5	13,1	13,1	Stock
OU8	ITM16	PPri41	13,73	62	65,10	0,77	3,00	0,052	0,524	3,4	5,2	18,0	Stock
OU9	ITM19	PPri47	1,30	6	64,83	2,87	1,48	0,057	0,446	0,0	12,0	3,0	Stock
OU6	ITM11	PPri32	16,52	74	66,89	1,73	0,96	0,132	0,051	3,4	21,3	3,5	2º Quarter
OU9	ITM20	PPri49	30,84	139	67,40	1,11	0,76	0,048	0,167	3,4	8,4	15,7	2º Quarter
OU5	ITM10	PPri30	26,60	120	66,52	1,59	1,80	0,041	0,104	4,0	9,0	3,0	3º Quarter
OU7	ITM12	PPri36	2,33	10	63,52	2,05	2,12	0,111	0,438	4,5	21,0	6,5	3º Quarter
Availability				450	66,28	1,45	1,55	0,067	0,243	3,6	11,0	10,0	-
Demand				450	66,28	1,45	1,45	0,055	0,290	3,0	6,0	20,0	

4º Quarter - PFin4													
Operation Unit	IOTP	Primary Product	Quant. (%)	Quant. (%)	Percentage (%)								Quarter Origin
					Fe	SiO_2	Al_2O_3	P	Mn	H_2O	OS	US	
OU8	ITM16	PPri41	28,74	99	65,10	0,77	3,00	0,052	0,524	3,4	5,2	18,0	Stock
OU9	ITM19	PPri47	4,87	17	64,83	2,87	1,48	0,057	0,446	0,0	12,0	3,0	Stock
OU9	ITM18	PPri45	7,92	27	66,31	2,20	1,01	0,057	0,314	3,4	8,4	15,7	3º Quarter
OU5	ITM10	PPri30	21,20	73	66,43	1,61	1,81	0,044	0,167	4,0	9,0	3,0	4º Quarter
OU6	ITM11	PPri32	24,89	85	66,80	1,72	1,11	0,123	0,124	3,4	21,3	3,5	4º Quarter
OU9	ITM20	PPri49	12,37	42	67,57	1,17	0,61	0,047	0,047	3,4	8,4	15,7	4º Quarter
Availability				343	66,20	1,45	1,75	0,068	0,269	3,3	11,0	10,0	-
Demand				343	66,28	1,45	1,45	0,055	0,290	3,0	6,0	20,0	-

Table 5 presents part of the solution generated by the mathematical programming model for the test problem. It shows the quarter's composition of 'PFin4'. It specifies in all quarters the amount and source of each of the Primary Products used to create this Final Product, as well as the amount available (availability) and the quality demanded (Demand) for the 'PFin4'. In this table, there are two hatched cells. The first one corresponds to the specification of 66.00% defined in Meet Goal and the second is related to the 30 kt imposed in "Impose Blending", both are described in Table 4.

5. Conclusions

This work presented a system that uses an optimization model based in Goal Programming to solve the Mining Production and Sales Planning (MPSP) of a Brazilian mining company. It was taken into account a year planning horizon distributed in quarters. In order to validate the model, a scenario that reflects real situations of an iron ore mining company located in the state of Minas Gerais, Brazil, was used. Despite the impossibility of making a comparative analysis between the solutions obtained by the system and those generated by the company in previous years due to the unavailability of previous data, the advantage of the system is clear when it is observed the amount of time taken to solve the proposed problem. Whereas the employee in charge would take about a week to analyze only one scenario and make a decision, the developed system needed only 15 seconds to find the best solution for that particular scenario.

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