Local and global optimisation in raw material processing

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***Abstract*—In this paper we are interested in the mine planning. The aims of this paper is to propose a new model of global optimization for bloc extraction and smelting furnace and then evaluate the advantage to use a global model rather than a set of local optimization. In fact, organizing a global optimization between mines extraction site and smelting furnace require a reorganization of the mines planning service and the smelting furnace planning service. Show the advantage of a global optimization approach is the first step of the process of a global optimization. The proposed model is capable of optimizing mining complexes and takes into account the possibility to produce different types of products thanks to production policies dictated by the processing plant.**

I. Introduction

The bulk of the literature deals with two principal types of mining exploitation: underground mining [1] and open pit mining [2]. We are interested in open pit mining. Most research in planning and scheduling aims to resolve problems linked to the open pit mining. In the literature, the principal problems are: the determination of the ultimate open pit limit (the determination of the sequence of extracted bloc) [3][4][5][6], the management of the mining process [7] and the global optimization solving [8][9]. These different types of problems present different types of methods of resolution. These methods which are mostly: simplex, metaheuristics are dictated by the constraints, the decisions and objectives specific to each problem. To the best of our knowledge, the two principal types of models to represent these problems are: local models [4][5] and global models [8][9]. To resolve the problem related to the determination of the ultimate pit limit and the determination of the sequence of extracted bloc, several algorithm are developed based on metaheuristic, such as ant colony [3]. Godoy and Dimitrakopoulos (2004) applied simulated annealing method on the effective management of waste mining and orebody grade uncertainty. In [7], Dimitrakopoulos and Goodfellow (2013), combined two metaheuristics : simulated annealing and particle swarm optimization algorithm. Concerning, problem related to the mine planning there is a method to minimize perturbation during re-planning: [10] proposed three alternative formulations of the MIP (Mix Integer Programming) model.

All the products are the results of complexes processes. These processes are principally : raw material extraction, transport and transformation. These processes required actors. There are different types of actors and different kinds of interactions between these actors. The actors are classified in two principal categories : suppliers and customers. The interactions between these actors are: demand and supply.

This article focuses on the first steps of a generic chain production that is to say the steps where extraction, processing raw material and selling mining products, takes place. These activities of extraction and processing raw material are optimized to increase profit generated by the selling activity.

Consequently and as we said before, the principal steps in optimization are: first, defining the problem that we should resolve then developing a model to represent the problem and finally proposing methods and algorithm to resolve the problem.

However a main aspect of an optimization is gathering information [11]. J.whittle in [11] presented the main actors and the principal informations that must be taking into account during an optimization process. Furthermore, communication between the actors is important that is to say every actors involved should be aware of the actions and results implemented in this endeavour. These different steps are complementary. Thus, in the literature, local models are used to represent local problems. These local models have a relatively low calculation time. However, we also find global models that aim to a global optimization of a mine complex. These global models closed to reality will give credibility to the associated optimization. However, some global models are simplified to avoid challenges associated with the global optimization(e.g. stockpile is not integrated to the model). Another aspect of the mine complex is the safety aspect: Tong Lei and Dou Yuanyuan,[12], proposed an approach by simulation to highlight the fact that investing in safety is benefic to the future. We understand that, preparing an accident will cost less expensive when it actually declare.

A common element of the different models that we have presented previously is the objective function. Indeed, the principal objective of the optimization of a mining process is to maximize profit. To optimize the activity of a mine complex, two approaches are possible : a global approach and a local approach. This paper aims to discuss the comparison between these two approaches. As a consequence, we have two local models and a global model. First, local models of extracting blocs, blending process and fusion process are proposed. The presentation of the different model and the implementation with generated data lead to several test. These test conduce to a comparison between profit generated by local and global approaches.

Before introducing the different local models and the global model, a description of the optimization context is presented. In the following section, the problem is described by a schema, in which, principal localizations, actors and processes are presented. To show the differences between the local and global approaches, a section about their comparison is developed. In this section, the results of the test is presented. Finally, conclusion and future extensions are presented.

II. Problem under study

By R Dimitrakoupolos [6], "...a mineral value chain is an integrated business...using a set of processing facilities". This set of facilities are linked by streams processes and materials. By materials we mean extracted materials (mining blocs), material between each facilities and products that are sold to costumers. These material flows are driven by processing streams, decisions on the destinations of the mining material and decision of using additives or not during the blending process. We notice that facilities are a set of mines and a set of processing plant. The materials are: ore materials and dopants (additives and neutral mining materials). In the model the processing streams are principally:

- Blending process and at the last stage of mineral value chain
- Fusion process in the smelting furnace

We notice that a set of mine $m \in \mathbb{M}$ have a capacity of n blocs. This capacity is given by a mine optimization by a LOM (Life Of Mine) software. Consequently, we have a possible sequence of blocs that could be extracted from a mine. However, in this model we supposed that during a horizon $\mathbb{T}$ a unique bloc is extracted in a given period $t \in \mathbb{T}$.
Moreover, we know the grades of ore in a mine so the grades of ore in a bloc. This paper aims to discuss and show differences between local and global optimization. However before introducing the comparison between these approaches, it is necessary to present the main process of this study: Extraction process and Transformation process.

A. Extraction process

1) The physical process: The activity of extraction blocs, includes physical processes and decision processes. The physical processes implies a production system, products and the production process.
The production system is principally composed by a set of mines and processing plants. Transport process is the link between extraction and transformation. However, this process is not modeled in this study. The extraction process also involves Human and material resources.
The physical process implies products. The products in inputs are the mines that is to say the waste dump and mining ore from each mines of the mineral value chain. In outputs of the extraction process, the mining ore is transferred to the processing plant downstream.
The production process involves in the extraction process decomposes into two sub processes:

- Extraction of waste dump
- Extraction of ore gross

The physical process of the activity of extraction implies decisions specific to each main decision-centers: extraction and transformation. the following paragraph focus on the decision of extraction.

2) The decision process: These processes require dedicated software [13], which can determinate the ultimate pit limit of an open pit mining and consequently the sequence of extracted blocs. The decisions to be taken, at this stage of the exploitation is to determine which blocs to be extracted or not. This decision depends heavily, on the cut-off grade which is a level below which the material is not "ore" and considered to be uneconomical to mine and process. This is also the minimum grade of ore used to establish reserves.

After this presentation of the extraction process, the transformation process is introduced in the following subsection.

B. Transformation process

1) The physical process: The production system involved into the transformation process uses a smelting furnace in which transformation occurs.

The process involves products:

- Inputs:
  - Mining material (outputs from the extraction process.)
  - Additives (dopants, neutral earth)
- Outputs:
  - Ore mixture (outputs from the blending process,c.f. next paragraph.)
  - Different mining products

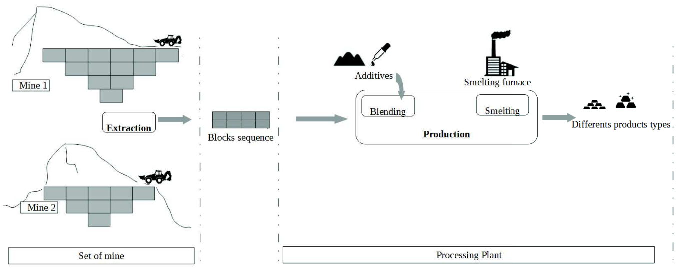
The production system and the products are linked by the production process. The production process involves in the transformation process is decomposed into three sub processes:

- blending process
- smelting process

These processes are leaded by decisions.

2) The decision process: Each entities are concerned with different decisions. The activity of extraction of blocs involved decisions on the sequence of extracted blocs. The processing plants are the centers where the decisions of additives to add and production policies to apply are taken in order to respect smelting furnace constraints.
In the local optimization of supplying a smelting furnace we have to satisfy ore's grade constraint imposed by the smelting furnace,we have to satisfy weight constraint and we must pay attention to the process of mixture before inclusion in the smelting furnace. At this stage (of the blending process, before fusion process), we have different possible scenarios.The first scenario is that in a period, a bloc is not extracted from a mine $m \in \mathbb{M}$, consequently we have a lake of bloc in the bloc sequence and we don't have a good grade of element in the mixture. To over pass this situation we add an additive which makes the mixture having

a grade of elements that is acceptable by the smelting furnace. The second scenario is that the mixture does not have the weight imposed by the smelting furnace, consequently we add to the mixture during the blending process an additive of neutral earth. By this way, the grade of elements in the mixture is stable but the total weight of the mixture is adjusted, so we respect constraint of the smelting furnace. The last scenario is that the last hypothesis is a globalization of the two past hypothesis that is to say, the mixture to include in the smelting furnace does not have an acceptable grade of element and also does not have an acceptable weight to satisfy the constraint of the smelting furnace. The figure below shows the general context of the optimization.



Generic schema of a mining complex

To summarize, in the context of a mining complex, we are concerned with the optimization of the process of blocs extraction in different mines and the transformation process of theses blocs in a smelting furnace. Thus the problem is to determine the optimal sequence of extraction of blocs and the production plocy of the smelting furnace (i.e. quantity of elements to be used, in grade and weight, to respect smelting furnace constraints). In this paper we discuss the differences between local and global optimization of these two processes.

III. LOCAL MODELS

In the literature, we find several models for local optimization which aim to:

- the sequence of extraction
- the optimal production under constraints on grade of elements

In the following section, we present the model which computes the sequence of extraction (section III-A) and then the model which computes production policy of the smelting furnace under constraints of elements grade and satisfaction of a demand. We notice that materials blocs are denoted by the subscriptions i or b.

A. *Exploitation of mines*

It is usually supposed in the literature that the time period correspond to the time to extract a bloc. The following model is under the same supposition. So, we want to find for a given mine the sequence of extracted bloc. In other worlds, we determine for each period $t \in \mathbb{T}$ the sequence of blocs that will be extracted.

Sets :

- $\mathbb{B}$: set of blocs $b \in \mathbb{B}$.
- $\mathbb{T}$: set of period t.
- $\mathbb{U}$: set of edge $(i, j), i, j \in \mathbb{B}$. This set is used to represent the precedence extraction constraints (2) (j must be extract before i).

Parameters :

- V_b : extracting value of bloc $b \in \mathbb{B}$.
- C_b : extracting cost of bloc $b \in \mathbb{B}$.

Decision variables :

- $x_{b,t} \in \{0, 1\}$: 1 if the bloc $b \in \mathbb{B}$ is extracted at period $t \in \mathbb{T}$ 0 else.

Objective-Function:

$$\max : \sum_{b=1}^{B} \sum_{t=1}^{T} (V_b - C_b).x_{b,t} \tag{1}$$

The constraints which define our problem are presented below.
Precedence constraint during the bloc extraction are represented by equation (2) and (3)

$$x_{i,t} \leq \sum_{w=1}^{t-1} x_{j,w}, \forall (i, j) \in \mathbb{U}, t = 2, ..., T \tag{2}$$

$$x_{i,1} \leq In_i, \forall i \in \mathbb{B} \tag{3}$$

Constraint (4) expresses that there is one and only one bloc extracted from different period t.

$$\sum_{b=1}^{B} x_{b,t} = 1, \forall t \in \mathbb{T} \tag{4}$$

Constraint (5) expresses that a unique bloc b is extracted in a period t.

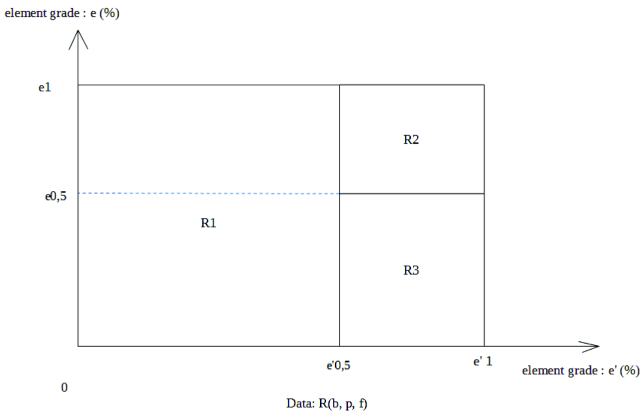
$$\sum_{t=1}^{T} x_{b,t} \leq 1, \forall b \in \mathbb{B} \tag{5}$$

We have presented in this paragraph, a problem of extracting bloc.

B. *Supplying a smelting furnace*

In the following section, we propose a model that represents the problem of the production policy of a smelting furnace under constraints of elements grade under a given stockpile structure and production condition depending on the grade of elements. More precisely the problem is to determine the production policy of the furnace for a given horizon taking into account the stockpile composition and the demand in product for this horizon. In this paper, we suppose that they is one stock pile for each mines and at each time $t \in \mathbb{T}$ a bloc of each mines are blended and then transfered to the smelting process.

Moreover, the production of a product depends on the grade of elements and the production policy of the smelting furnace. So, for each period t we must identify which product can be made. The figure below illustrates the case of 3 production conditions for a given production policy of the furnace and two elements.

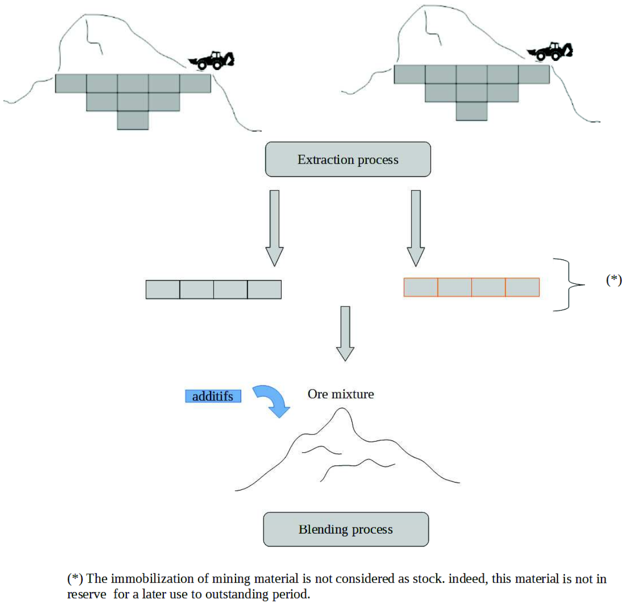


We notice :

- R1 : $\begin{cases} 0 \leqslant e' \leqslant e'0,5 \\ 0 \leqslant e \leqslant e1 \end{cases}$
- R2 : $\begin{cases} e'0,5 \leqslant e' \leqslant e'1 \\ e0,5 \leqslant e \leqslant e1 \end{cases}$
- R3 : $\begin{cases} e'0,5 \leqslant e' \leqslant e'1 \\ 0 \leqslant e \leqslant e0,5 \end{cases}$

Thus a production policy is determined by the grades of elements in a bloc. This figure shows a set of three production campaign (R1, R2, R3) with constraints on two elements grades (e,e'). We could have more than two elements and consequently a representation with more than a traditional two-dimensional view.

In the context of local optimization each mines sends a list of bloc which will be delivered at each period. From the list of each mines with the characteristic of each bloc and the information of product demand the planning service of smelting furnace is able to choose the production policy of the smelting furnace which minimize the cost of adding additives or neutral raw material to satisfy the constraints of grade of elements.



The figure above illustrates the fact that there is no stock in the global process. We only find an immobilization of mining materials.

In this local model we do not consider stockpile, before the fusion process. The blocs are in a blending process to respect constraint of weight and grade imposed by smelting furnace. Having the mine source of a bloc and its period extraction could be enough to identify a bloc. That is because we have an unique extraction bloc per period. However, over the production horizon $\mathbb{T}$, a number of the bloc should be extracted. Moreover, in this local optimization, we consider a matrix $Be_{b,t,m}$ that is used to specify the extracted blocs.

Sets :

- $\mathbb{T}$: set of period t.
- $\mathbb{M}$: set of mine m.
- $\mathbb{B}$: set of blocs b.
- $\mathbb{J}$: set of elements j.
- $\mathbb{P}$: set of products p.
- $\mathbb{F}$: set of production policy of the smelting furnace f.
- $\mathbb{I}$: set of production condition i.

Parameters :

- $Be_{b,t,m}$: $Be_{b,t,m} = 1$ if a bloc $b \in \mathbb{B}$ is extracted at a period $t \in \mathbb{T}$ else $Be_{b,t,m} = 0$ if the bloc is not extracted. It is the information send buy the mines extraction service
- G_j^{max} : maximum grade of elements j of the ore mixture imposed by smelting furnace.
- G_j^{min} : minimum grade of elements j of the ore mixture imposed by smelting furnace.
- $G_{b,j,m}$: grade of element j in a bloc b from a mine m.

- C^d : dopant's cost.
- C^n : neutral raw material's cost.
- C_p^{Br}: breaking cost of product $p \in \mathbb{P}$.
- C_p^I : stock cost of product $p \in \mathbb{P}$.
- Pr_p : selling price of products $p \in \mathbb{P}$.
- Br_p^{init} : quantity of unavailable product $p \in \mathbb{P}$ before the production.
- I_p^{init}: stock of product $p \in \mathbb{P}$ before the production.
- $Tr_{j,i}^{min}$: minimal grade of elements j to be produced with condition i.
- $Tr_{j,i}^{max}$: maximal grade of elements j to be produced with condition i.
- $R_{i,p,f}$: quantity of product $p \in \mathbb{P}$ from a blending mixture satisfying the production condition i $t \in \mathbb{T}$ for the production policy$f \in \mathbb{F}$ of the smelting furnace.
- D_p : demand of product $p \in \mathbb{P}$.

Variables :

- Br_p : quantity of unavailable product $p \in \mathbb{P}$ at the end of horizon.
- I_p: stock of product $p \in \mathbb{P}$ at the end of horizon.
- $G_{t,j}^m$: grade of element j of ore mixture at period t.
- T_t^D : quantity of dopant to be added to respect minimum grade G_{min} of elements j imposed by smelting furnace.
- T_t^N : quantity of neutral raw material to add to respect maximum grade G_{max} of elements j imposed by smelting furnace.
- $a_f \in \{0,1\}$: 1 if we apply the production policy $f \in \mathbb{F}$, 0 else.
- $Y_{p,t}$: variable defining quantity of product $p \in \mathbb{P}$ to produce in a sequence $t \in \mathbb{T}$ and from a bloc $b \in \mathbb{B}$.
- $Pc_{i,t,f}$: 1 if ore mixture of period $t \in \mathbb{T}$ satisfy the production condition $i \in \mathbb{I}$ for the production policy $f \in \mathbb{F}$, 0 else.

Objective-Function:

$$\begin{aligned} \max : \quad & \sum_{t=1}^{T}\sum_{p=1}^{P}(Pr_p.Y_{p,t}) \\ & - \sum_{p=1}^{P}(C^{Br}.Br_p + C^I.I_p) \\ & - \sum_{t=1}^{T}(C^n.T_t^N + C^d.T_t^D) \end{aligned} \tag{6}$$

subject to:

The equation (7) shows the constraint of satisfaction of the demand.

$$I_p^{int} + Br_p + \sum_{t=1}^{T} Y_{p,t} = D_c + Br_p^{int} + I_p, \forall p \in \mathbb{P} \tag{7}$$

Constraint (8) defining the production of product p at the period t.

$$\sum_{b=1}^{B}\sum_{f=1}^{F}\sum_{i=1}^{I} Pc_{i,t,f}.R_{i,p,f} = Y_{p,t}, \forall t \in \mathbb{T}, \forall p \in \mathbb{P} \tag{8}$$

Constraint (9) defining that there is one and only one production policy of smelting furnace f at each period.

$$\sum_{f=1}^{F} a_f = 1 \tag{9}$$

Constraint (10) defining that if we have the production policy of smelting furnace f the production condition $Pc_{i,t,f}$ can be satisfy only for the composition of production policy f.

$$Pc_{i,t,f} \leq a_f, \forall i \in \mathbb{I}, \forall t \in \mathbb{T}, \forall f \in \mathbb{F} \tag{10}$$

Constraint (11) Compute the grade of each element$j$ at each period t.

$$G_{t,j}^m = 1/M.\sum_{m=1}^{M}\sum_{b=1}^{B} Be_{b,t,m}.G_{b,j,m} + T_t^D - T_t^N, \forall t \in \mathbb{T}, \forall j \in \mathbb{J} \tag{11}$$

Constraint (12) expresses the constraints of minimum grade of elements dictated by the smelting furnace.

$$G_{t,j}^m \geqslant G_j^{min}, \forall t \in \mathbb{T}, \forall j \in \mathbb{J} \tag{12}$$

Constraint (13) expresses the constraints of maximum grade of elements dictated by the smelting furnace.

$$G_{t,j}^m \leqslant G_j^{max}, \forall t \in \mathbb{T}, \forall j \in \mathbb{J} \tag{13}$$

Constraints (14) and (15) verify if the grade of each elements j of the ore mixture at the period t satisfy the production condition i.

$$Pc_{i,t}.Tr_{j,i}^{min} \leq G_{t,j}^m, \forall t \in \mathbb{T}, \forall j \in \mathbb{J}, i \in \mathbb{I} \tag{14}$$

$$G_{t,j}^m \leq Tr_{j,i}^{max} + (1 - Pc_{i,t}).100, \forall t \in \mathbb{T}, \forall j \in \mathbb{J}, i \in \mathbb{I} \tag{15}$$

Constraint (16) expresses the constraints that at each period t the ore mixte satisfy only one production condition.

$$\sum_{i=1}^{I} Pc_{i,t} = 1, t \in \mathbb{T} \tag{16}$$

IV. Global model of raw material extraction, processing on smelting furnace and selling products

To propose a global model we suppose a configuration with a not significant stock of material for the smelting furnace.However, we have a stock of neutral materials and dopants which are included in $\mathbb{A}$.These additive elements are used to satisfy capacity constraints and grade constraints of the smelting furnace. This last could be seen as the bottleneck of the mineral value chain. So we have a basic mine process that is to say from the extraction to the transformation at the smelting furnace with a unique extracting bloc per period from different mines. The model does not focus on local optimization that is commonly presented in general literatures but on global optimization model coupling the extractions decision, the production policy of the smelting furnace and blending process.
A period $t \in \mathbb{T}$ is a complete processing production: from raw material extraction to the transformation giving products which are sold to costumers. Consequently, to a period we could associate a bloc extracted from a mine and more generally a sequence of blocs because of the set of mines $m \in \mathbb{M}$.

For example if T=5 then we have a campaign production going from t=1 to T=5, ie a period total of extracting blocs with a length of 5. In this example extracting blocs speed time is 1 bloc per mine, if we have 3 mines m_1, m_2, m_3 ,we have three blocs for a period t and for the total period T we have fifty blocs.Each three groups (three mines sources)of five blocs have a particular grade of elements.As a result, for a period t we have three ore material blocs from the three mines to blend, each bloc have an element grade that is required for the blending process and imposed by the smelting furnace.

A. Model

Sets :

- $\mathbb{J}$: set of elements $j \in \mathbb{J}$.
- $\mathbb{M}$: set of mine $m \in \mathbb{M}$ for the blending process.
- $\mathbb{B}_m$: set of blocs $b \in \mathbb{B}_m$ of mines $m \in \mathbb{M}$. A unique bloc is extracted at each period $t \in \mathbb{T}$ and from a unique mine, with a unique grade of element.
- $\mathbb{P}$: set of products p.
- $\mathbb{T}$: set of period t.
- $\mathbb{F}$: set of possible production policy of smelting furnace f.
- $\mathbb{U}_m$: set of edge $(i, j), i, j \in \mathbb{B}_m$ which represent the precedence extraction constraints (j must be extract before i). see constraint (14))below

Parameters :

- M: Number of mine.
- $C_{b,m}$: extracting cost of bloc $b \in \mathbb{B}_m$ of mines $m \in \mathbb{M}$.
- G_j^{max} : maximum grade of elements j of the ore mixture imposed by smelting furnace.
- G_j^{min} : minimum grade of elements j of the ore mixture imposed by smelting furnace.
- $G_{b,j,m}$: grade of element j in a bloc b from a mine m.
- C^d : dopant's cost.
- C^n : neutral raw material's cost.
- C_p^{Br}: breaking cost of product $p \in \mathbb{P}$.
- C_p^I : stock cost of product $p \in \mathbb{P}$.
- Pr_p : selling price of products $p \in \mathbb{P}$.
- Br_p^{init} : quantity of unavailable product $p \in \mathbb{P}$ before the production.
- I_p^{init}: stock of product $p \in \mathbb{P}$ before the production.
- $Tr_{j,i}^{min}$: minimal grade of elements j to be produced with condition i.
- $Tr_{j,i}^{max}$: maximal grade of elements j to be produced with condition i.
- $R_{i,p,f}$: quantity of product $p \in \mathbb{P}$ from a blending mixture satisfying the production condition i $t \in \mathbb{T}$ for the production policy$f \in \mathbb{F}$ of the smelting furnace.
- D_p : demand of product $p \in \mathbb{P}$.

Decision variables :

- $x_{b,t,m} \in \{0, 1\}$: 1 if the bloc $b \in \mathbb{B}_m$ of mines m is extracted 0 else, at a period $t \in \mathbb{T}$.
- Br_p : quantity of unavailable product $p \in \mathbb{P}$ at the end of horizon.
- I_p: stock of product $p \in \mathbb{P}$ at the end of horizon.
- $G_{t,j}^m$: grade of element j of ore mixture at period t.
- T_t^D : quantity of dopant to be added to respect minimum grade G_{min} of elements j imposed by smelting furnace.
- T_t^N : quantity of neutral raw material to add to respect maximum grade G_{max} of elements j imposed by smelting furnace.
- $a_f \in \{0, 1\}$: 1 if we apply the production policy $f \in \mathbb{F}$, 0 else.
- $Y_{p,t}$: variable defining quantity of product $p \in \mathbb{P}$ to produce in a sequence $t \in \mathbb{T}$ and from a bloc $b \in \mathbb{B}$.
- $Pc_{i,t,f}$: 1 if ore mixture of period $t \in \mathbb{T}$ satisfy the production condition $i \in \mathbb{I}$ for the production policy $f \in \mathbb{F}$, 0 else.

The goal of the objective function is to maximize profit by choosing at a period t, the best blocs b from a mine m to be extracted and the best products to produce. Between the bloc extraction and the activity of selling products, we must respect blending constraint imposed by the smelting furnace. Concerning the constraints of the global model, we have all the constraints of the local models but we consider a set of several mines.

Objective-Function:

$$\begin{aligned}\max :\ & \sum_{t=1}^{T}\sum_{p=1}^{P}(Pr_p.Y_{p,t}) \\ & -\sum_{p=1}^{P}(C^{Br}.Br_p + C^{I}.I_p) \\ & -\sum_{t=1}^{T}(C^{n}.T_t^{N} + C^{d}.T_t^{D}) \\ & -\sum_{m=1}^{M}\sum_{b=1}^{B_m}\sum_{t=1}^{T} C_{b,m}.x_{b,t,m}\end{aligned} \tag{17}$$

Subject to:

$$x_{i,t,m} \leq \sum_{w=1}^{t-1} x_{j,w}, \forall (i,j) \in \mathbb{U}, t = 2,...,T, \forall m \in \mathbb{M} \tag{18}$$

$$x_{i,1,m} \leq In_i, \forall m \in \mathbb{M}, \forall i \in \mathbb{B}_m, \tag{19}$$

$$\sum_{b=1}^{B} x_{b,t,m} = 1, \forall t \in \mathbb{T}, \forall m \in \mathbb{M} \tag{20}$$

$$\sum_{t=1}^{T} x_{b,t,m} \leq 1, \forall m \in \mathbb{M}, \forall b \in \mathbb{B}_m \tag{21}$$

$$I_p^{int} + Br_p + \sum_{t=1}^{T} Y_{p,t} = D_c + Br_p^{int} + I_p, \forall p \in \mathbb{P} \tag{22}$$

$$\sum_{b=1}^{B}\sum_{f=1}^{F}\sum_{i=1}^{I} Pc_{i,t,f}.R_{i,p,f} = Y_{p,t}, \forall t \in \mathbb{T}, \forall p \in \mathbb{P} \tag{23}$$

$$Pc_{i,t,f} \leq a_f, \forall i \in \mathbb{I}, \forall t \in \mathbb{T}, \forall f \in \mathbb{F} \tag{24}$$

$$\sum_{f=1}^{F} a_f = 1 \tag{25}$$

$$G_{t,j}^{m} = 1/M.\sum_{m=1}^{M}\sum_{b=1}^{B} x_{b,t,m}.G_{b,j,m} + T_t^{D} - T_t^{N}, \forall t \in \mathbb{T}, \forall j \in \mathbb{J} \tag{26}$$

$$G_{t,j}^{m} \geqslant G_j^{min}, \forall t \in \mathbb{T}, \forall j \in \mathbb{J} \tag{27}$$

$$G_{t,j}^{m} \leqslant G_j^{max}, \forall t \in \mathbb{T}, \forall j \in \mathbb{J} \tag{28}$$

$$Pc_{i,t}.Tr_{j,i}^{min} \leq G_{t,j}^{m}, \forall t \in \mathbb{T}, \forall j \in \mathbb{J}, i \in \mathbb{I} \tag{29}$$

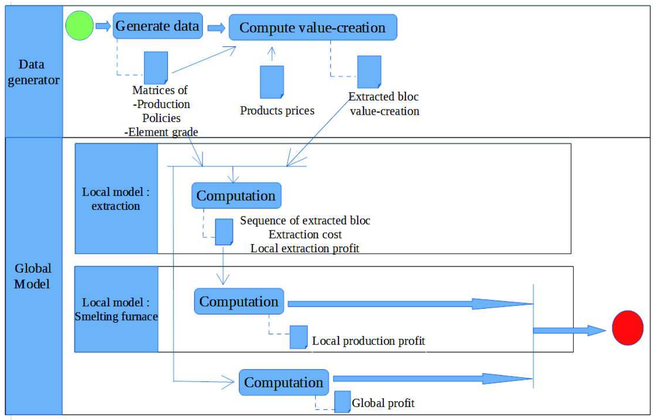
$$G_{t,j}^{m} \leq Tr_{j,i}^{max} + (1 - Pc_{i,t}).100, \forall t \in \mathbb{T}, \forall j \in \mathbb{J}, i \in \mathbb{I} \tag{30}$$

$$\sum_{i=1}^{I} Pc_{i,t} = 1, t \in \mathbb{T} \tag{31}$$

After the presentation of the different models, the following section deals with the test in order to highlight the comparison between the two approaches. First, a description of the test process is presented, then the result is presented and finally these previous observations lead to the analyze of the test.

V. Comparison between local and global optimization approach

A. *Test process description*



Description of the test Process

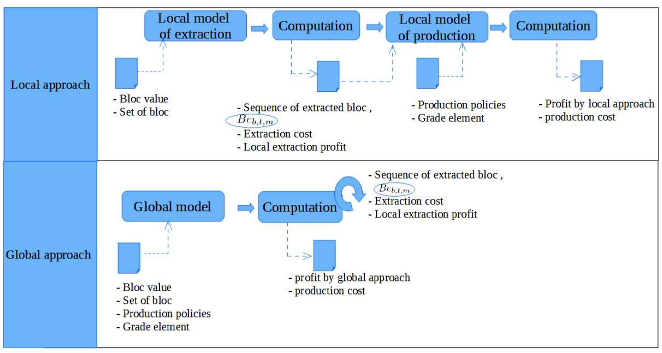
In the figure shown above, the link between global and local approaches is the sequence of the extracted blocs. Indeed, in the global approach, we resolve at the same time : the problem of extracted bloc and the problem of the production at the processing plant (with the smelting furnace).The global model integrate the set of mines in inputs and compute in the same time the sequence of extracted blocs and the productions.In the local approach, firstly, we compute the extracted blocs from the local model of extraction then we save it in a matrix $Be_{b,t,m}$. Secondly, we integrate $Be_{b,t,m}$ in the local model of the smelting furnace's supply model. Consequently, in the global approach we resolve at the same time all the problems of each decision centers (extraction and production) whereas in the local approach we resolve step by step and independently each problems. The test process include three models. A model that represents the problem of extraction, a model that represent the problem of production and a global model. To analyze the difference between global and local approach, we have simulated a value-creation and computed the global optimization for 50 instances for 3 sizes of horizon with a mine complex composed of two mines. The process test is detail in the previous figure. For each test, we randomly generate data. More precisely, the matrix that characterizes production policy is generated for

each test. This matrix gives the quantity of each product p produced for a production policy of melted metal satisfying the characteristics on grade of elements. Another matrix that characterizes the grade of element in an extracted bloc is also generated. This matrix assigns a percentage of each element e at each bloc b. From these matrices, we compute the value-creations of the extracted blocs. A matrix with the value-creation of the blocs is an input of the local model of extraction. The local model of extraction computes the extraction cost and the sequence of the extracted blocs. The sequences of the extracted blocs is an input for the local model of smelting furnace. This local model computes the profit of the production and selling activity. To compute the global profit, we subtract the cost of the extracting blocs to the profit of the production and selling activity.
We notice that value creation is computed by the following formula:

$$V_b = (\sum_{pl=1}^{Pl} Bt_p.Y_{p,pl,b} - \sum_{e=1}^{E} Cd_e Cd_e.q_{e,b})/pl \qquad (32)$$

We have the following notification: pl the index of production policy, $Y_{(b,pl)}$ the quantity of product p for production policy pl produced from the bloc b and $q_{(e,b)}$ the quantity of dopant of element e required to satisfy the smelting furnace constraints. We notice that for the valuation, we consider the blocks separately from each other since the DM of smelting furnace does not know the sequence of bloc and neither with which bloc of the other mines it will be blended.

To evaluate if it is possible to increase the performances, we compute the optimal solution using a global optimization model (global approach) which determines simultaneously the extraction decision dopant adding and the production policy in order to maximize the objective function. These inputs give a logical link between the global and local optimization (local approach). Consequently, we are able to make comparison between local and global optimization. We illustrate our remarks with the following figure.



$Bc_{b,t,m}$: Link between local and global approach

B. Test results

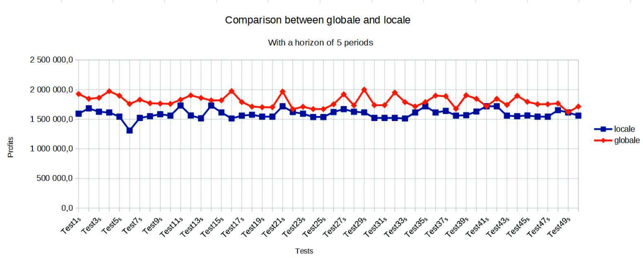
After making fifty tests with data generated randomly, we show that profit generated by a global approach is better than a local approach. The datas generated are:

- Production policy
- Element grade

The data computed from the previous data are:

- Value-creation with the formula (32)
- Element grade

The figure above shows the profits between local and global approaches for a horizon of five periods. The others tests are for horizons of six and nine periods. We have the same observation: a global approach is better than a local approach.



It is interesting to see that the gap between global and local approach is not stable. The next table shows that in average the gab between local and global approach is at 7,42 percent. However, we find a maximum gap for 34,27 percent.

	maximum	average	minimum
local / Global	34,27%	7,42%	0,00%

VI. Conclusion and persqpectives

We proposed a new model for a global approach that allowed production of different products at the end of the mineral value chain. With this approach, we pursue the goal of increasing profit. In other words, we try to reduce cost generated by the activity of the mining complex. However, this study is the first step of our study. The next steps consist in including uncertainty in the model. As far as we know the uncertainty of the capacity of extraction is not well studied in the literature.Moreover, it will be interesting to propose a model that guarantees stable profit whatever disruptions.
In order to ensure optimal and stable benefit, we propose to implement the model previously presented with uncertainty on the capacity of extracting bloc. An approach by scenario will be proposed for a next study. Furthermore, to deal with the uncertainty, a representation of these uncertainty is required. Representation by the theory of possibilities, is a way of modelization of these lack of information on key factors in mineral value chains.

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