ROBUST OPTIMIZATION FOR MINE PLANNING

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ABSTRACT: *In this paper, we are interested in mine planning under uncertainty on the capacity of extraction in a mine complex. Indeed, in real life there is always a gap between planned activities and activities carried out during the period. In this paper, we determine the quantity of loaded mining materials, transported mining materials and processed mining materials in order to minimize the impact of uncertainty into the mining production chain. In order to achieve this challenge, we proposed a model to represent the mining complex. This model takes into account the uncertainty on the capacity by the use of scenarios. In order to face the uncertainty on the capacity of extraction we propose a robust approach with the MaxMin decision criterion. To the best of our knowledge, while the bulk of the literature treats the optimization in mining complex with stochastic approaches, this paper uses a robust approach under uncertainty. A case study using data from a nickel laterite company is used in order to implement the proposed model under uncertainty on capacity.*

KEYWORDS: *uncertainty, scenario, mine planning, MaxMin criterion*

1 INTRODUCTION

A mining complex could be considered as a supply chain system where material is transformed from one processing plant to another. Indeed, a typical mining complex "will include a number of mines, a number of processing plants and a number of products" [1]. In this context different kinds of uncertainty in the mining complex have been identified in the literature: the geological uncertainty [2], which includes the uncertainty on the ore grade [3], the uncertainty on the cut-off grade [4] and the uncertainty on metal [5]. Besides the uncertainty around the element grade, the uncertainty on the metal price, operating cost [6] and the uncertainty on supply and demand [7] have been considered.
Different kinds of planning decisions in the optimization of the smelting furnace impact the mine complex in various levels horizons. There are short-term, middle-term and long-term decisions. In this paper, we focus on middle-term decisions.
The determination of the open pit limit involves the decision of considering a bloc as a waste or not [8]. The determination of the sequence of blocs involves the decision of considering one or another period for the extraction of blocs [11]. Finally, the common objective of these decisions is to maximize the profit or to maximize the production.

As we can see, in the bulk of the literature, ore grade uncertainty is well studied. Indeed, one of the principal problem in the optimization of a mining complex is to determine the design of the open pit limit [8], [9], [10]. The determination of the open pit limit is dependent on the valuation of a mining bloc. The valuation of a bloc is computed from the planned profit on a bloc. This planned profit value takes into account the quantity and quality of products that a bloc could produce and the cost of the operations (extraction, transportation and the transformation).
After the determination of the open pit limit, the principal problem is the determination of the sequence of the extracted blocs [11], [12], [13]. In this context, the problem is to determine the best period for a set of blocs to be extracted and the best extraction order of these blocs. The period and the order of extraction are factors that could increase generated profit.
In this paper, the objective is to maximize the production of the processing plant more precisely of the smelting furnace, which is the critical

resource of the processing plant, with minimal cost. This maximization is done knowing the sequence of extracted blocs.
In this paper the uncertainty is integrated by taking into account different scenarios. Stochastic approaches have been proposed to address the problem of uncertainty on ore grade [2], [3] and [4]. In this context of uncertainty, a probability distribution on the state of the world is assessable. Hence this approach consists in considering that the different scenarios have equivalent probabilities. In such, so called, stochastic approaches, the optimization consists in choosing the maximum value in average. To the best of our knowledge, the bulk of the literature goes ahead optimization with stochastic approaches. In this paper, a robust approach is proposed. In decision theory, the following classical decision criterions are: the criterion of Wald (1950) or Maximin criterion, the Maximax criterion, the Hurwicz criterion, the regret minimization criterion or MinMax criterion, the Leximin and Leximax criterions, and the Laplace criterion [15].
Our study focuses on the MaxMin criterion, which minimizes the maximal cost between planned solutions and real solutions. Indeed, in this paper we focus on the uncertainty of capacity of extraction and we try to reduce the impact of the uncertainty on the mining complex.

The remainder of this paper is organized as follows. In the following section, we introduce the context of the study. In the next section, we introduce the proposed deterministic model in deterministic context then the model under uncertainty on capacity. In this section, the notations and assumptions for the models are provided. In the following section, a numerical test is conducted to show the efficiency of the robust approach with the use of the MaxMin criterion. Finally, the conclusions and future works are outlined.

2 CONTEXT OF THE STUDY

In this study we are interested on the exploitation of the mine complex. The mine complex is composed of a set of mines, a set of processing plants with stock areas, a calcination plant and a smelting furnace. In the figure 1, we illustrate the general context of this study. The extracted blocs from each mine are stored at the seaside. At this place, the mining material could be considered as blended and it is also stated that it is not possible to extract more than the capacity of extraction, which is composed of specifics trucks and specific workforce. From this place, transportation is scheduled in order to supply the processing plant. Such as for the extraction process, it is not possible to transport more mining material than the capacity of transportation which is composed of a set of boats and trucks. The transportation is the link between mines and the processing plant which is composed of stock areas, a calcination plant and a smelting furnace. In this study each mine has an order of bloc extraction, so called: “sequence of extracted blocs” and the smelting furnace is considered as the customer of the system under study.

As we said before, this study focuses on the uncertainty of capacity at the mine. Indeed, in real life, there is a gap between the quantities planned by the mines decision makers and the real extracted quantities. More precisely, we are interested on the uncertainty due to a hurricane which could happen in a short and well known period: for instance in New Caledonia from January to March. Hurricanes stop the extraction (of one mine) and the transportation from this mine to the furnace. We cannot predict the hurricanes so the uncertainty on the occurrence of hurricanes induces an uncertainty on the capacity of the mining process (only the periods are known).
Thus, the problem is: how to plan the extraction and the transportation to guarantee a realistic production of the furnace? In other words, the problem is to plan the production of the furnace such that the production of furnace by period will be realizable for all scenarios (due to the uncertainty).
There is the possibility to increase the extraction capacity after a hurricane but this induces extra cost. Hence, we look for an extracting, transportation and production plan, which can be adaptable to uncertainty for a minimal cost. The solution will be a balance between safety stocks and corrective decisions (that could increase the extraction capacity).

We have presented the context of the paper: planning optimization under uncertainty on capacity. In the next sections, we propose a deterministic model to represent the proposed optimization problem without uncertainty then a model under uncertainty on the capacity. In this context, we use the MaxMin criterion to optimize the mining complex.

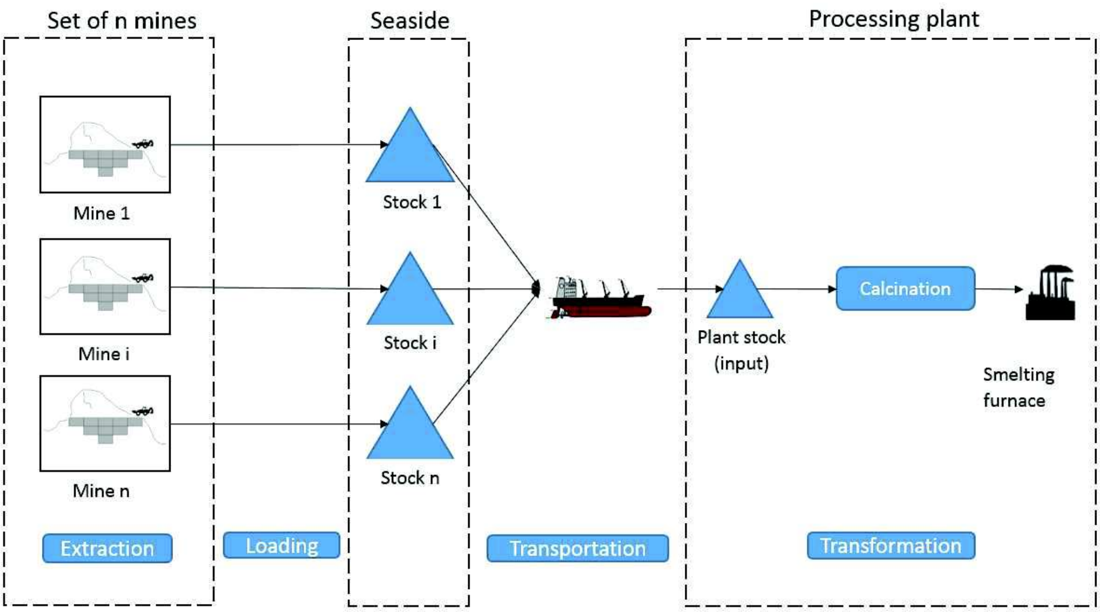

Figure 1: Context of the study

3 DETERMINISTIC MODEL

In this section, we propose a deterministic model, which will be generalized to the uncertainty in next section. In the determinist model it is assumed that a bloc is extracted within one period.

An optimization model is presented bellow with the description of the sets, the decision variables and the constraints. This description highlights the characteristics of the model that have been presented in the previous sections.

Sets

$\mathcal{M}$: Set of mines,

$m = 1, \ldots, M$ $\quad m \in \mathbb{N}$

$\mathcal{T}$: Set of periods,

$t = 1, \ldots, T$ $\quad t \in \mathbb{N}$

Decision variables

$PEx_{m,t}$: Quantity of extracted material in a mine m at a period t

$I_{M_{m,t}}$: Inventory of mining ore in a mine m at a period t

$Ld_{m,t}$: Quantity of mining ore at the seaside in a mine m at a period t

Tr_t: Quantity of mining material transported from the seaside to the processing plant at period t

I_{P_t}: Processing plant inventory at a processing plant at a period t

Cal_t: Quantity in calcination process at a period t

W_t: Losing material at a period t

F_t: Demand of the smelting furnace at a period t

$x_{PEx_{m,t}} \in \{0,1\}$: 1 if $PEx_{m,t}$ is extracted 0 else

Parameters

$ubPEx_{m,t}$: Capacity of extraction of the mine m, at a period t

$CPEx_{m,t}$: Cost of availability of mining ore in a mine m at a period t

$CI_{M_{m,t}}$: Cost of inventory of mining ore in a mine m at a period t

$CLd_{m,t}$: Cost of transportation of mining ore from a mine m to the seaside at a period t

CTr_t: Cost of transportation of mining ore from seaside to the processing plant at a period t

$UTr_{m,t}$: Capacity of transportation in a mine m at a period t

CI_{P_t}: Cost of the plant inventory at a period t

$CCal_t$: Cost of calcination at a period t

Pr_t: Selling price at a period t

α: Index of loose of H^2O during the calcination process

LF_t , UF_t : Maximum and minimum of capacity of the smelting furnace at a period t

In this deterministic context the objective of the optimization is to maximize the production at the smelting furnace with minimal cost. This goal is characterized by the following objective-function and the constraints of the model.

Objective-function:
Maximize:
$$\sum_{t\in T} F_t * Pr_t - \sum_{m\in M}\sum_{t\in T} PEx_{m,t} * CPEx_{m,b} + I_{M_{m,t}} * CI_{M_{m,t}} + Ld_{m,t} * CLd_{m,t}) - \sum_{t\in T}(Tr_t * CTr_t + I_{P_t} * CI_{P_t} + Cal_t * CCal_t) \quad (0)$$

Subject to:

Equations (1), (2) shows the link between the quantity of extracted mining material in a mine m at a period $t(PEx_{m,t})$, inventory of the end of the precedent period $t-1(I_{M_{m,t}})$, and the outflow $(Ld_{m,t})$ at the loading zone.

$$PEx_{m,1} = I_{M_{m,1}} + Ld_{m,1} \quad t = 1, \quad \forall m \in \mathcal{M} \quad (1)$$

$$I_{M_{m,t-1}} + PEx_{m,t} = I_{M_{m,t}} + Ld_{m,t} \quad \forall m \in \mathcal{M}\ \forall t \in \mathcal{T} \quad (2)$$

Equation (3) shows the loading constraint at seaside for the transportation to the processing plant.

$$\sum_{m\in\mathcal{M}} Ld_{m,t} = Tr_t \quad \forall t \in \mathcal{T} \quad (3)$$

Equations (4)(5) represents the link between the inventory at the end of a period *t*, the inventory from precedent period $(I_{P_{t-1}})$ the transport to the processing plant inventory (Tr_t) and the quantity of calcined mining material (Cal_t).

$$Tr_1 = I_{P_1} + Cal_1 \quad (4)$$
$$Tr_t + I_{P_{t-1}} = I_{P_t} + Cal_t \quad \forall t \in \mathcal{T}\backslash\{1\} \quad (5)$$

Equations (6)(7) compute the quantity of lost mining material during the calcination process.

$$W_t = Cal_t * \alpha \quad \forall t \in \mathcal{T} \quad (6)$$
$$F_t = Cal_t * (1-\alpha) \quad \forall t \in \mathcal{T} \quad (7)$$

Equation (8) represents the capacity of extraction.

$$PEx_{m,t} = ubPEx_{m,t} \quad \forall t \in \mathcal{T} \quad (8)$$

Equation (9) represents the capacity constraint of the transportation.

$$Tr_{m,t} \le UTr_{m,t} \quad \forall t \in \mathcal{T} \quad (9)$$

Equation (10) represents the capacity constraint of the smelting furnace.

$$LF_t \le F_t \le UF_t \quad \forall t \in \mathcal{T} \quad (10)$$

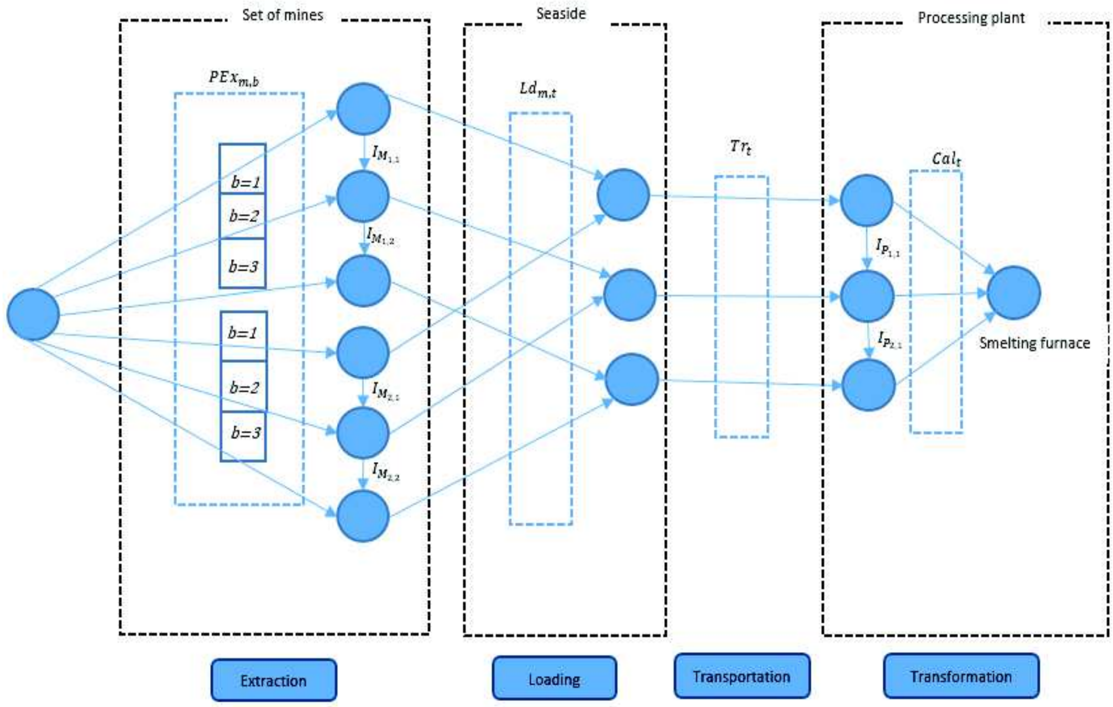

Figure 2: Deterministic approach

4 ROBUST APPROACH

4.1 Approach under uncertainty

In this paper we deal with uncertainty on the extraction capacity. This capacity may decreased due to the meteorological conditions. For instance in New Caledonia from January to march, hurricanes often stop the extraction (of one mine) and the transportation from this mine to the furnace. Thus, the problem is “how to plan the extraction and the transportation to guarantee the well production of the furnace?”. In this study we assume that the occurrence of the hurricane cannot be predicted (only the period where it is possible to have one are known). Moreover the extraction and transportation plan can only be adjusted after the hurricane is passed: for instance it is possible to increase the capacity after a hurricane. Indeed, during the hurricane there is a work stoppage, and after the hurricane overtime or temporary staff can be used. Due to the uncertain nature of a hurricane this increase of working hours cannot be planned before the occurrence of the hurricane.

Thus, to take the uncertainty into account, different scenarios are considered according to the possible periods of occurrence of the hurricanes and their impacts on the capacity.

So in the robust model, we want to have a stable flow through the furnace with maximal value and minimal cost. Hence the decision variable F_t is not scenario dependent but all other variables are scenario dependent. For instance, $I_{M_{m,t}}$, becomes $I_{M_{m,t,s}}$ as the stock value depends on the scenario.

A scenario is a variation of extraction capacity due to a hurricane. Hence we need to distinguish the real quantity of extracted materials and the maximal capacity of extraction. Indeed, in robust model we need to:

- Distinguish the bloc and the period so $PEx_{m,t}$ become $PEx_{m,b,s}$ where b is the block number as well as the period of extraction of this bloc for the nominal plan (without damage),
- Introduce a new decision variable $Ex_{m,b,t,s}$ which is the quantity of bloc b of mines m extracted at period t in scenario s
- Add parameter $ubEx_{m,t,s}$ which is the real capacity of extraction at mine m at period t in scenario s.

In the figure 3, we represent the flow graph of the robust model.

In this study, the robust approach consists in choosing the best decision on the extraction, loading, transportation, storing, in order to catch a stable quantity in input for the smelting furnace. Concerning the scenarios in which we have damage and cause an increase of capacity or a decrease of capacity we have levers: to make more stock or to increase workforce with temporary work contract and overtime. The last solution is not use as a rule because it is too expensive for a society. Thus, the levers, which increase capacity, are considered. In the proposed model, the extra capacity is modeled at constraint (24) with the variable: $Ks_{m,t,s}$.

In this optimization context the optimization consists in computing solution that takes into account the scenarios. An apparition of damage characterizes a scenario during the horizon. Before the observation of the damage, the mine production system follows the nominal plan without damage (the different scenario dependent variables are equal for all scenarios). After undergo of a damage, a new plan is computed. Hence, the scenario dependent variables for a scenario in which the damage appears are now different than the ones of the nominal plan. The objective is to propose a realizable plan for the smelting furnace for all the scenarios so that the variable linked to the smelting furnace is not scenario dependent.

The figure 4 bellow illustrates the process of computation of new values of the scenario dependent variables at the moment of observation of a damage that is taking into account in the single proposed robust MIP model.

As shown in figure 3, we find two main parts in the model. The first part is dependent of the scenario; this is the part, which deals with the extraction, transportation and blending process. The part, which is not scenario dependent, is the one, which deals with the smelting furnace.

In deterministic context, we only find a planned mining material. Indeed, in deterministic context, planned activity is equal to realized activity.

4.2 Model under uncertainty

We have presented the general context of the optimization under uncertainty, in the previous

section; we introduce now the proposed robust model.
The presentation of the model proceeds as follow. First, we give the context of the optimization by introducing the notations of new variables and parameters and finally we introduce the objective function and the constraints of the different constraints.

Sets
$\mathcal{T}_d$: Set of periods after observation of a damage at period $d \in T$

Decision variables
$Ex_{m,b,t,s}$: Real quantity of extracted material in a mine m at a period t
$Ks_{m,t,s}$: Over capacity of production in a mine m at a period t

Parameters
$CEx_{m,b,t,s}$: Cost linked to the real quantity of extracted material in a mine m at a period t
CKs : Cost linked to the over capacity of production in a mine m at a period t

The objective-function traduces the goal of the optimization. On the one hand, the goal is to minimize the cost associated to the exploitation of the mine complex (extracting cost, storing cost, loading cost, transportation cost, calcination cost, and extra cost of extra capacity). On the other hand, the objective is to maximize generated profit.

Objective-function:
Max:

$$(\sum_{t\in T} F_t * Pr_t - \max_{s\in S}(\sum_{m\in M}\sum_{t\in T}\sum_{b\in B}(Ex_{m,b,t,s} * CEx_{m,b,t,s} + I_{M_{m,t,s}} * CI_{M_{m,t,s}} + Ld_{m,t,s} * CLd_{m,t,s}) - \sum_{t\in T}(Tr_{t,s} * CTr_{t,s} + I_{P_{t,s}} * CI_{P_t} + Cal_t * CCal_t) - \sum_{m\in M}\sum_{t\in T} Ks_{m,t,s} * CKs)$$

This objective can be linearized as follow:
Max: $\sum_{t\in T} F_t * Pr_t - H$

$$H \geq \sum_{m\in M}\sum_{t\in T}\sum_{b\in B}(Ex_{m,b,t,s} * CEx_{m,b,t,s} + I_{M_{m,t,s}} * CI_{M_{m,t,s}} + Ld_{m,t,s} * CLd_{m,t,s}) - \sum_{t\in T}(Tr_{t,s} * CTr_t + I_{P_{t,s}} * CI_{P_t} + Cal_t * CCal_t) - \sum_{m\in M}\sum_{t\in T} Ks_{m,t,s} CKs) \quad \forall s \in \mathcal{S}$$

Constraints (11), (12), (13) imposed the extraction of the maximum of removable mining material in a mine m at a period t before the extraction of the removable mining material in a mine m at a period *t+1* for a scenario *s*.

$$PEx_{m,b,s} \leq ubPEx_{m,b,s} - x_{PEx_{m,b,s}} \quad \forall m \in \mathcal{M}, \forall b \in \mathcal{B} \ \forall s \in \mathcal{S} \qquad (11)$$

$$PEx_{m,b,s} \geq (1 - x_{PEx_{m,b,s}}) * ubPEx_{m,b,s} \quad \forall m \in \mathcal{M}, \forall b \in \mathcal{B} \ \forall s \in \mathcal{S} \qquad (12)$$

$$PEx_{m,b+1,s} \leq ubPE_{m,b+1,s} * (1 - x_{PEx_{m,b,s}}) \quad \forall m \in \mathcal{M}, \forall b \in \mathcal{B}\backslash\{B\} \ \forall s \in \mathcal{S} \qquad (13)$$

Constraint (14) represents the link between the quantity *($PEx_{m,b,s}$)* of removable mining material in a mine m at a period t and the effectively extracted in several periods for a scenario *s*.

$$PEx_{m,b,s} = \sum_{t=1}^{T} Ex_{m,b,t,s} \quad \forall m \in \mathcal{M}, \forall b \in \mathcal{B}, \forall s \in \mathcal{S} \qquad (14)$$

Constraints (15) and (17) express that before the observation of damage there is the same extracted and loaded materials.
Equation (16) represents the constraint of capacity for the real extraction of mining material in a mine *m*, for a bloc b and at a period t for a scenario *s*. $\forall s \in S \ ubEx_{m,b,d_s,s} = 0$ it means that there is no extraction during period d_s.
Thus $Ks_{m,t,s} = 0 \ \forall s \in \mathcal{S}, \forall t \in \{\mathcal{T} | t < d_s\}$, $\forall m \in M$, which means that no overcapacity is used before a Hurricane.
Constraint (18) shows the link between loaded mining materials ($Ld_{m,t,s}$) and transported mining materials ($Tr_{t,s}$) from seaside to the processing plant. Indeed, all the loaded mining materials are transported.

$$Ex_{m,b,t,s} = Ex_{m,b,t,s'} \quad \forall m \in \mathcal{M}, \forall b \in \mathcal{B}, \forall s, s' \in \mathcal{S} \quad \forall t \in \{\mathcal{T} | t < d_s \cap t < d_{s'}\} \qquad (15)$$

$$\sum_{b\in B} Ex_{m,b,t,s} \leq ubEx_{m,t,s} + Ks_{m,t,s} \quad \forall m \in \mathcal{M}, \quad \forall t \in \mathcal{T}, \forall s \in \mathcal{S} \qquad (16)$$

$$Ld_{m,t,s} = Ld_{m,t,s'} \quad \forall m \in \mathcal{M}, \forall s, s' \in \mathcal{S}, \quad \forall t \in \{\mathcal{T} | t < d_s \cap t < d_{s'}\} \qquad (17)$$

$$Tr_{t,s} = \sum_{m=1}^{M} Ld_{m,t,s} \quad \forall t \in \mathcal{T}, \forall s \in \mathcal{S} \qquad (18)$$

Constraints (20), (21) show the link between the quantity $(Ex_{m,b,t,s})$ of extracted mining material in a mine m at a period t, inventory of the end of the precedent period $t-1$ ($I\_M_{m,t,s}$), and the outflow ($Ld_{m,t,s}$) at the loading zone for a scenario s.

$$Ex_{m,1,1,s} = I_{M_{m,1,s}} + Ld_{m,1,s}$$
$$b = 1, t = 1,\ \forall m \in \mathcal{M}, \forall s \in \mathcal{S} \quad (20)$$

$$I_{M_{m,t-1,s}} + \sum_{t=b}^{B} Ex_{m,t,b,s} = I_{M_{m,t,s}} + Ld_{m,t,s}$$
$$\forall m \in \mathcal{M}, \forall t \in \mathcal{T}\backslash\{1\}, \forall s \in \mathcal{S} \quad (21)$$

Constraints (22) (23) represent the link between the inventory (I_{P_t}) at the end of a period t and for a scenario s, the inventory ($I_{P_{t-1}}$) from precedent period the transport (Tr_t) to the processing plant inventory and the quantity (Cal_t) of calcined mining material.

$$Tr_{1,s} = I_{P_{1,s}} + Cal_1$$
$$\text{initialisation: } t = 1\ \forall s \in \mathcal{S} \quad (22)$$

$$Tr_{t,s} + I_{P_{t-1,s}} = I_{P_{t,s}} + Cal_t$$
$$\forall t \in \mathcal{T}\backslash\{1\} \forall s \in \mathcal{S} \quad (23)$$

Constraints (24) (25) compute the quantity W_t of lost mining material during the calcination process at period t.

$$W_t = Cal_t * \alpha \qquad \forall t \in \mathcal{T} \quad (24)$$
$$F_t = Cal_t * (1-\alpha) \qquad \forall t \in \mathcal{T} \quad (25)$$

Equation (26) represents the capacity of the smelting furnace at period t.

$$LF_t \leq F_t \leq UF_t$$
$$\forall t \in \mathcal{T} \quad (26)$$

We have presented in the previous section the deterministic model and the model under uncertainty. In the next section, we illustrate the implementation of these models on data from a nickel industry. We describe the input data and finally we analyze the output data and the results.

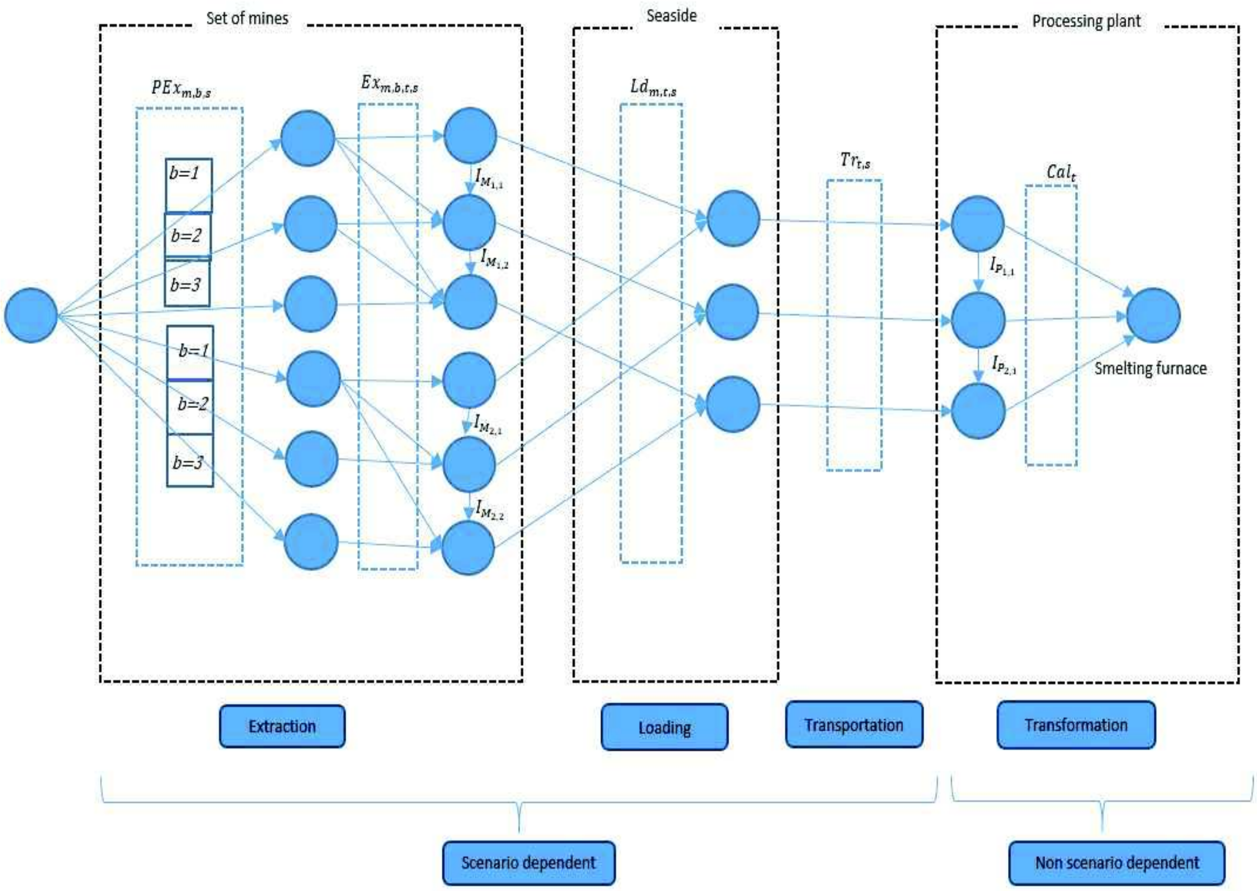

Figure 3: Robust approach

5 CASE STUDY

The application that is discussed is for a laterite-mining complex. The laterite-mining complex is localized in a zone where the risk of occurrence of a hurricane is high. This risk is the consequence of the meteorological uncertainty. The purpose of this example is to implement the Maximax criterion.

5.1 Description of the input data

In order to implement the model, we took into account a set of twelve periods and two mines.
The proposed robust approach is tested through a series of seven scenarios. The first three scenarios concern the case where the first mine is impacted. The first scenario takes into account a hurricane emerging in March, the second scenario with a hurricane emerging in April and the third scenario takes into account a hurricane emerging in May. As we consider a set of two mines for the tests, there are also three scenarios for the second mine according to the period of occurrence of the hurricane (March, April or May). Moreover, we consider a scenario in which there is no hurricane observed.

5.2 Description of the experimental process

The objective of the experimental process is to compare the robust approach and the classical approach (re-planning).
In real life, we usually find the classical approach. This approach consists in a re-planning when damage occurs.
The robust approach consists in the computation of a production plan that takes into account a set of scenarios. The tests are done as follow. First, we compute a production plan under uncertain context by taking into account a set of scenarios. Secondly, we generate a set of production plans, on the one hand with re-planning and on the other hand by taking into account each scenario.
The re-planning has been done as follow.

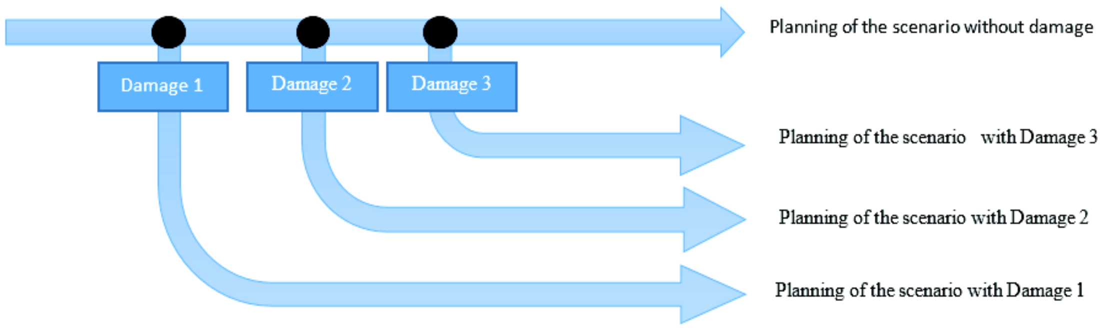

Figure 4: Illustration of the re-planning

We consider a set of damages with a period of occurrence of these damages. As shown in figure 4, first, we generate a production plan in a context without damages, then we consider the occurrence of a first damage. Before this first damage, the variables have the same values as in a production plan without damages. After the occurrence of damage we re-planned the production and we have new values for the variables. The variables linked directly to the smelting furnace are not scenario dependent, they are stable.
The first period of occurrence of a damage is t=5. We save the generated solution for this first re-planning process. Another re-planning process is done for a damage at period t=6 ant at period t=7.
Finally, we choose the production plan that generates the maximum of profit and we compare this solution to the robust solution.
In the next section, we analyze the obtained results.

5.3 Analysis of the result

The different values of the input data are presented is figure 5.

Input data	
Furnace Capacity	600 000
Transport Capacity	800 000
Initial stock	400 000
Final stock	400 000

Figure 5: Input data

The costs that are taking into account in the objective-function are: the stock cost at the mines, the stock cost at the processing plant and the extra capacity cost. It should be noted that the extra capacity of extraction is possible at 30 % of the real capacity.

We have compared the profits generated by a robust approach and by the different re-planning (that takes into account each different damages). The results show that for damage at period t=5 (hurricane in December), robust approach is better at 77%, for a damage at t=6 (hurricane in January) robust approach is better at 52% and for a damage at t=7 (hurricane in February) robust approach is better at 37%.

As we said before the best result is obtained with damage in February (t=7). We compare the classical approach (with re-planning, figure 6) and robust approach (MaxiMin criterion, figure 7). The figures bellow, show the evolution of the stock at the processing plant and the evolution of the extra-capacity for a damage in February. We can see that for the robust approach, we have a better stability in the consumption of the stock.

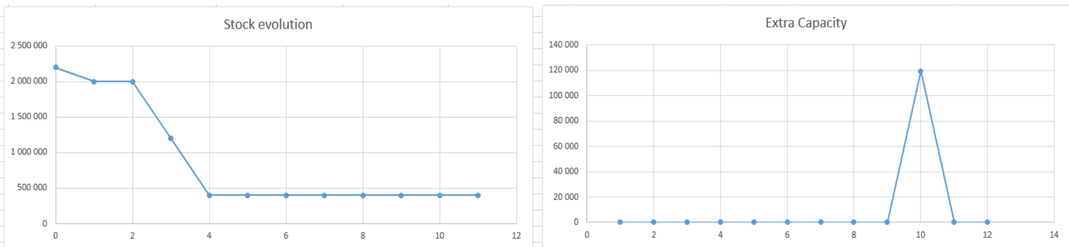

Figure 6: Stock and extra capacity in February; classical approach

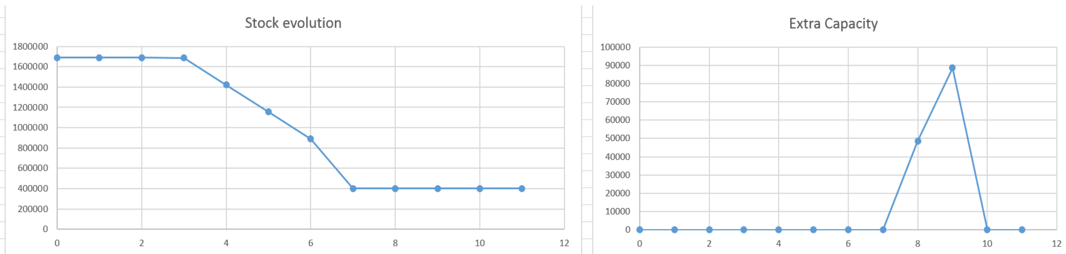

Figure 7: Stock and extra capacity in February; robust approach

6 CONCLUSION AND PERSPECTIVES

This paper is the first paper under our knowledge that applies such a robust approach in order to optimize a mining complex. In this purpose, the MaxMin criterion has been used. The proposed approach is a new way of thinking the optimization of a mining complex. Indeed, with this decision criterion, decision maker belief is taken into account. Indeed, the different scenarios that have been tested result from the industry expertise. In the future, we propose to develop a model that deals with the grade of element. Indeed, in real life, the concentration of an element influences the fusion speed in the smelting furnace. As other perspective, we will apply other decision criterions as min max Regret or leximin in order to optimize a mining complex and will make comparison between them.

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