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# USING ONTOLOGICAL REPRESENTATION IN THE COPPER LEACHING DOMAIN FOR OPERATION MODE PLAN RECOMMENDATION

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**Abstract:** The performance of a leach heap is directly related to the planning of the processes related to the exploitation of the heap. Efficient planning must consider mineral resources and operating conditions to provide an optimal and realistic strategy for copper extraction and processing. Carrying out the task of planning modes of operation requires a significant effort in information generation, analysis and design. Once the operating mode plans have been made, it is important to make decisions to select the most appropriate one, and in this context, having an intelligent system that supports the planning and decision making of the operating mode is important for the industry. of copper in Chile. This work presents the design of the ontological representation of knowledge to support the development of a prototype of a recommendation system for modes of operation in mining, which allows optimizing the planning of a copper leaching process in heaps.
**Keywords:** Ontological representation, Recommendation system, Heap leaching, Planning of mining operation modes.

## INTRODUCTION

Industry 4.0 is changing the way businesses operate, particularly in the copper production company, this forces companies to compete in a way to deliver greater value to the customer [1, 2]. This implies that companies must combine advanced operation and production techniques with intelligent technologies, to achieve a better integration of people and resources in the production of assets [3].

Currently, artificial intelligence tools and industry 4.0 are a great support for mining processes and especially for those processes where the aim is to obtain the greatest benefit with the least social impact as described in works such as [4, 5]. Industry 4.0 is also touching copper mining [6], integrating tools that support better management and production of mining knowledge as expressed in works such as [7].

To date, in the copper production industry by processes such as leaching, work has traditionally been done with pyrometallurgy and hydrometallurgical methods [9, 10], with hydrometallurgy having the lowest environmental impact [3, 10]. A method that has been gaining interest in mining is leaching. There are several processes to leach minerals, this depends mainly on the physical and chemical characteristics of the mineral, according to previous works such as [5, 10], this directly impacts the planning of the mode of operation to leach, and therefore on the quality of the asset production and final profitability.

Normally, carrying out the task of planning modes of operation requires a significant effort in information generation, analysis and design, where multiple factors such as those mentioned above participate. Therefore, the selection of the appropriate mode of operation for the production of copper by leaching is a very important aspect for current mining.

In this document we report the representation of the knowledge that is part of the development of a prototype of an intelligent recommendation system that is based on previous works such as [11], but that is 100% oriented to the general characteristics of production by leaching in the Chilean mining. Specifically, this prototype is aimed at supporting decision-making for the selection of operating modes in copper heap leaching.

The final objective of the development of this prototype system is to be able to complement the set of tools used in making strategic decisions in mining production processes. This could mean an improvement in the efficiency of mining production, without incurring a significant increase in investment. To achieve the above, this document describes the proposal for representing the knowledge used in the generation of operation plans, through the use of ontologies.

## WORK CONTEXT AND WORK IN ADVANCE

Smart mining is the path taken by the mining industry in Chile, which involves the adoption of technologies and tools that make autonomous and more productive mining possible [4, 7]. Currently, the cost of production has increased due to factors such as the decrease in the grade of minerals, the price of commodities, labor and capital, etc. [7]. But with the use of techniques such as leaching, production margins can be improved; in fact, it is estimated that around 20% of the world's copper is currently produced using the leaching process [12]. In Chile, heap leaching is mainly used for low-medium grade material (0.3 – 0.7%), to process oxides and currently also secondary sulfides [3, 12, 13].

Heap leaching can be based on solvent extraction, for the separation of different substances in hydrometallurgical solutions, and on electrowinning, which separates copper from the rest using a low-intensity direct electric current. In both, various data are considered that directly impact leaching, some of which are [10]: grade of material, leaching-ratio, irrigation-ratio, reagent(s), degree of CO3, number of days (of operation in the pile), granularity and stack height. These are related to concepts such as pile, material to be leached, reagent and technique.

In this work, two types of heap leaching are considered: (1) dynamic leaching: the main characteristic of this type is that after a while the debris is removed and replaced by fresh material, and (2) static heap leaching, where the material is not removed and is used to facilitate the leaching of new material that is added to the heap.

Also, the process involves analytical models to establish (calculate) the mode of operation. For this, the characteristics of the material in the pile and other important elements such as size (physical dimensions) of the pile, etc. are considered. that allow calculating optimal operation time and amount of copper to be recovered [12, 13].

These analytical models are formalized in mathematical formulas that are already established in the industry [15]. These formulas produce values of variables that are input to the process that will be incorporated into the method that is being proposed to evaluate the operation plans. In this work the model described in formula (1) is being used:

$$\frac{dy}{d\tau} = -k_T y n^T \qquad (1)$$

Where y is a dynamic quantity, such as concentration or recovery, k$T$ is the kinetic constant and n$T$ is the order of the reaction. The data obtained from analytical models can be complemented with Artificial Intelligence techniques for the treatment of uncertainty, a technique that has been applied in previous works such as that described in [16].

As stated in the introduction, the knowledge necessary to generate and select an operation plan for a heap leach can be represented in the form of ontologies. An ontology can be simply understood as a semantic representation of knowledge in a specific domain [14]. In the domain of mining, specifically in the leaching of copper, the composition of the material to be leached is an important factor. In the literature you can find previous works where ontological representation has been used in the mining domain, for example in [17, 18] this technology has been used to represent multi-sources of heterogeneous data (concepts, relationships between concepts, etc.…) relating to mining exploration. This type of representation techniques are also being used to house abundant and complex geological and/or satellite information that is useful in mining exploitation processes, as reported by authors in works such as [19-21].

## ELEMENTS OF ONTOLOGY

With the above described, the advanced work consists of an ontological representation of knowledge following previous works such as [12]. The interest in this representation focuses on the heap leaching process. The concepts are shown in Figure 1, the most important ones and their relationships are briefly described below.

Pile: accumulations of mineralized material that is made in a mechanized way, forming a type of continuous cake or embankment of varying height. The piles are slightly inclined to allow the runoff and collection of the solutions; they are irrigated with a solution of reagents to extract the mineral. Mode of operation: configuration of productive resources, in order to adapt to the characteristics of the feeding.

For this knowledge model, three modes have been considered, Mode_A, Mode_B..., Mode_X, where each one represents a mode, with Mode_X being the last possible operating mode to select. For the present work and as a simplification aimed at achieving the ontological representation close to a computational implementation, it has been decided not to give interest to the detail of the mode of operation in terms of its preparation. The entities, their characteristics and axioms considered based on the simplification described above are described below.

Type of mineral: solid inorganic substance, formed by one or more defined chemical elements that are organized into an internal structure. In previous works such as [22] it is established that leaching with material such as chalcopyrite (Chalcopyrite) can be highly profitable in chalcopyrite concentrations greater than 90%. This knowledge can be represented in the ontology as a constraint feature that uses the material concentration to alleviate and is compared to a threshold value of 90% material concentration.

Reagent: chemical element that establishes an interaction with other substances within the framework of a chemical reaction, generating a substance with different properties that is called a product. The reagents considered are sulfuric acid for oxidized minerals, while chloride and/or boric acid are considered for sulfide minerals.

Operating conditions: state of the variables of interest in a certain operating mode. The variables considered are shown in Figure 1, some of them are: days of operation, rate of irrigation, type of reagent and total reagent added. Ore recovery, updating the amount of ore extracted from the pile. Recovery is obtained through field measurements and/or predictions according to analytical models.

Relationships between classes have been defined to facilitate the work of identifying the most appropriate modes of operation for a pile and its material characteristics, pile size, etc. Figure 2 details the relationships considered, some of them are described below.

It-is-a-CO: relationship between concepts that belong to the same hierarchy.

depends-on: relationship established between the concepts involved in copper recovery.

Leaching: relationship between leaching agents and the type of material, Mode-of-operation: relationship between mode of operation and pile. As has been said, oxides are leached (LXoxide) or sulfides are leached (LXsulfides).

Form-of-Operation: relationship between mode of operation and stack. Establishes the mode of operation that must be applied to a stack according to its characteristics. The inverse relationship is given by operaSegún (see figure 2).

For the purposes of this document and

considering the simplifications applied to the production process, axioms have been defined that express specific restrictions or characteristics of the heap leaching process followed (generally) by mining companies that apply this process. Some of these axioms are described below.

Axiom-1: Let OM1 and OM2 be operating modes and let P1 and P2 be leach piles. OM1 and OM2 exist independently of the way a stack is operated, and OM1or OM2 can be applied on P1 or P2 under the following conditions:

1. If OM1 and OM2 are applied at the same time in P1 and P2 $\Longrightarrow$ OM1 = OM2.

2. If P1[1] $\neq$ P2 and OM1 is applied at P1 and OM2 is applied at P2 $\Longrightarrow$ OM1[1] $\neq$ OM2

Axiom-2: If P1, P2 are Stacks and OM1, OM2 are operation modes and if OM1 corresponds to P1, and OM2 corresponds to P2, then: $P1 \cap P2 = \emptyset$.

Axim-3: if P1 is a Heap Leaching and OM1, OM2 are operating modes, and P <oper>OM1 y P<oper>OM2, therefore: OM1$\neq$OM2, where <oper> represents the one-to-one correspondence of the operation of a stack according to an operation mode.

Axiom-4: if P1, P2 are leach heaps, M1, M2 and C1, C2 are the type of mineral and the operating conditions of the heap respectively, and furthermore, it is known that

C1<corresp>P1, C2<corresp> P2 and M1$\neq$M_2, therefore, $C1 \cap C2 = \emptyset$.

In which <corresp> represents the relationship that exists between a Pile where there is a specific type of material, and for that material in the pile, operating conditions are established.

Algorithms have been designed to select and recommend an operation mode and have been reported in [12]. To house the information related to the recommendation of the mode of operation to be recommended, an axiom has been designed to ensure the uniqueness of the recommendation, as follows:

Axiom-5: being OM1, OM2 modes of operation, the relationship <better than_OM> exists such that the following is true:Si OM1 < better than _OM> OM2 $\Longrightarrow$ it is recommended: OM1

1. Si OM2 <better than _OM> OM1 $\Longrightarrow$ it is recommended: OM2

2. Si (OM1 < better than _OM> OM2) and (OM2 <better than OM> OM1) $\Longrightarrow$ OM1== OM2

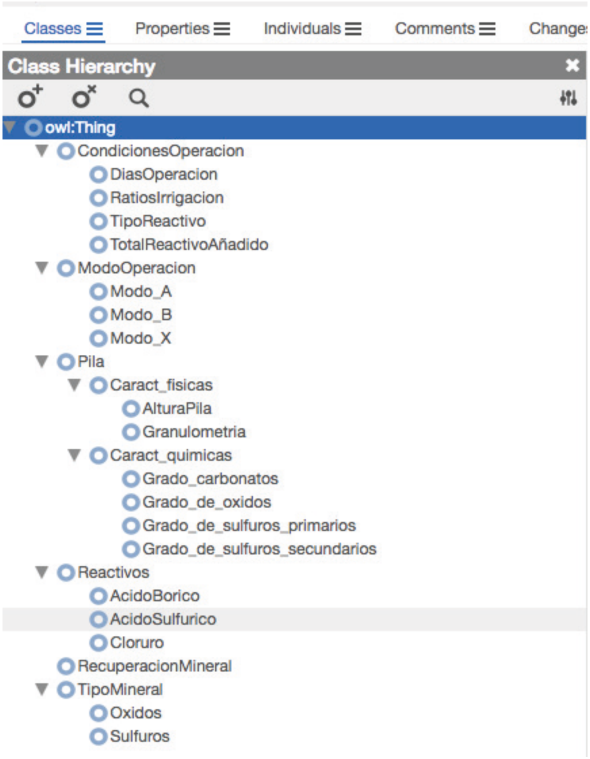


Figure 1 – Hierarchy of Ontology Classes for definition of Operation Modes

Another important element to achieve the model is the availability of data to generate the operation mode recommendation model. In this sense, historical data is available for the assembly phases of a leach heap, the seasonal phase and the disposal phase of a leach heap.

For the development of the work, the experience of an expert in the domain of leaching in copper heaps is also counted on to generate the rules that the knowledge model will have to infer and select the most appropriate model according to the characteristics of the material to be leached, times and operating restrictions.

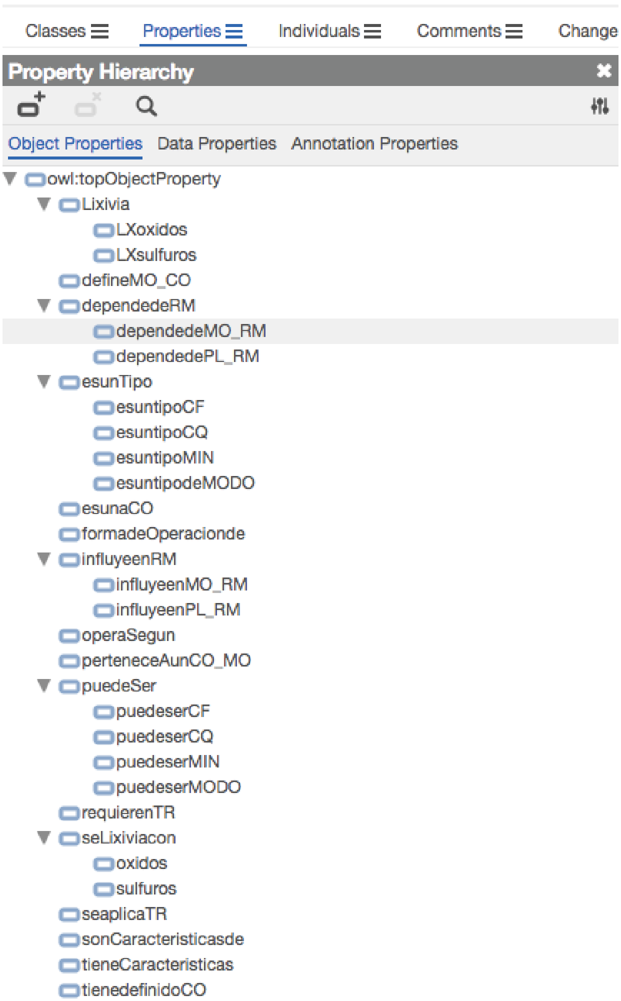


Figure 2 – Hierarchy of Properties associated with the Classes of the ontological representation

## CONCLUSIONS AND FUTURE WORK

This document has described the proposed representation of: concepts, relationships between these concepts, restrictions on these relationships and also axioms to be considered in the representation. This representation has been designed with the objective of supporting the proposed intelligent system in prototype version of a recommendation system for selecting the mining operation mode related to the heap leaching process.

As said in the introduction, in this work a recommendation system for selecting operation mode plans is being generated, inspired by intelligent recommendation systems in this domain. Therefore, this representation aims to support those in charge of selecting the best mode of operation, taking into account valuable historical information such as previous plans and results achieved, characteristics of the material to be leached and selected operation plans, in addition to the results. obtained with said plans. The representation described in this document uses the ontology technique and is therefore a very intuitive and easy-to-use form of semantic representation for highly technical personnel such as designers of exploitation plans in the production of copper by the leaching method.

In the computational design of the work being developed to build the prototype described above, two general stages are considered: Select operation plan and Recommend operation plan. The representation described in this work can support both tasks so that the objective associated with the mining industry is achieved, which must comply with standards of what we know as industry 4.0.

Thus and in detail, for the Select operation plan task, rules have been designed and represented to identify the best operation plan according to the characteristics of materials and the leaching process. Likewise, and for the Recommend operation plan task, the entities have been designed in such a way that the recommended operation plan can be shown (output of the first task), and also the explanation of the reason for that recommendation. For the representation of elements related to this task, previous experiences have been used where models for presenting information of interest have been developed.

As a future line of work, the following tasks can be highlighted: first the validation of the ontological representation described above, with the participation of an expert in copper leaching processes; Second, the validation of the ontological representation and its practical usefulness in the operation plan recommendation prototype. For this second task, the development of evaluation metrics applicable to the validation described in the previous lines is also contemplated as future work.

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