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# Effectiveness of optimization strategies to improve productivity and safety in open pit mines: protocol for a systematic review

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**Abstract**

Mining industry importance stems from the fact that it forms the basis of all materials used by humankind, including civil construction, pharmaceutical preparations, and the agro-industrial sector, where products such as phosphates are behind a significant part of all modern agriculture. Despite its high economic importance, the constraints of its activity make it one of the most challenging and dangerous industries. The main optimization problems in open pit mining design consist on the determination of the ultimate pit limit for exploitation, and mining block sequences for the production schedule, where safety management decision system needs to be integrated. The proposed protocol provides the procedure that will be used to conduct one or more systematic reviews according to the PRISMA statement, to prove the effectiveness of optimization solutions on open pit mining production and occupational safety. The search will be carried out in seven electronic engineering databases, using eight combinations of appropriate keywords for the topic to achieve the main goal. The selection process, data extraction, and data synthesis are described. Outcomes of this study will contribute to the mining industry through research to improve planning and safety in the long term and short term.

## 1. INTRODUCTION

Mineral resources are extracted from the ore bodies using different surface or underground mining methods. Surface mining is dominant, accounting for about 90% of the extracted raw materials (Rahmanpour & Osanloo, 2017).

Open pit mining although considered as an essential economical industry, is also one of the most dangerous industrial sectors for work, reporting a large number of accidents (Chen, Li, Chang, Sofia, & Tarolli, 2015).

Mine construction involves the consideration of the different constraints that can affect mining production. A proper mine planning can ensure the right conditions for safety, high productivity of the workers, and the mine as a whole. The main problems in open pit mine design and planning are, the determination of the Ultimate Pit Limit (UPL) of exploitation (Coelho et al., 2012), the pushbacks and the Mining Block Sequences (MBS) (Moosavi & Gholamnejad, 2016; Mousavi, Kozan, & Liu, 2016; Sari & Kumral, 2016) which are typically defined under certain geotechnical stability constraints (Zevgolis, Deliveris, & Koukouzas, 2018), and the maximum economic value (Navarra, Montiel, & Dimitrakopoulos, 2018; Upadhyay & Askari-Nasab, 2017). All this process involves the integration of safety management decision system considering mining law and safety standards (Sanmiquel, Bascompta, Rossell, Anticoi, & Guash, 2018).

The most used optimization solutions for open pit mining design are Lerchs & Grossman algorithm (LG) (Lerchs H and Grossman IF, 1965), and Push & Relabel algorithm (PR) (Goldberg & Tarjan, 1988). LG and PR algorithms were applied and compared (Hochbaum & Chen, 2000), where PR has shown superior performance in open pit mining problems, and LG has shown better performance in the use of system time and reducing storage requirements. Another successful method is the Ant colony ACO (Shishvan & Sattarvand, 2015;Gilani & Sattarvand, 2016) which has the capability of considering any objective function in the optimization process, thus being able to improve the Lerchs and Grossman algorithm and parametrization. Optimization mining solutions target various geological and operating constraints. Some address the maximization of the Net Present Value NPV of mining projects (Samavati, Essam, Nehring, & Sarker, 2017; Whittle, Brazil, Grossman, Rubinstein, & Thomas, 2018). Others address the consideration of sustainable development aspects “economic, social, environmental and lately safety” (Kazanin, Rudakov, & Kolvakh, 2018), which are firmly related to the UPL, explaining the needs to consider them in mine planning and mining design for a sustainable mining industry (Adibi, Ataee-Pour, & Rahmanpour, 2015; Kamenopoulos, Agioutantis, & Komnitsas, 2018; Popovic et al., 2015; Rahmanpour & Osanloo, 2017; Xu et al., 2018).

The primary purpose of this research protocol is to identify the new strategies in open pit mining design, their objective functions, their impact on short-term and long-term mine planning and their effectiveness to overcome occupational risks and to increase safety in the surface extractive industry. In this context, no systematic review was found.

## 2. METHODS

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols (PRISMA-P) will be used to guide the reporting of this protocol (Moher et al., 2015).

### 2.1. Eligibility criteria

Studies will be selected according to the criteria outlined below:

- Type of study: The study will include articles focused on any open pit mine with or without transition into underground mining, focusing on UPL and MBS problems.
- Interventions: Any partial or global optimization solution implemented in open pit mine with or without transition into underground mining to solve UPL and MBS problems.
- Comparators: The study will compare the optimization solutions according to their objective function, implementation, performance, the parameters considered in each one, and their evidence in safety terms.
- Outcomes: Any kind of economical, technical or environmental or safety outcomes related to open pit optimization will be considered.
- Study designs: The studies that will be included are those addressing global or partial optimization of open-pit mines, implemented on site, as well as case studies with combined exploitation.
- Time frame: Any implemented optimization method in the extraction stage of the mining life cycle will be selected.
- Setting: No setting restrictions.
- Years considered: The study will include studies published from January 2009 to January 2019.
- Language: The study will consider only the articles written in English.
- Publication status: Only research articles published in peer-reviewed journals will be selected.
- Exclusion criteria: The study will exclude non-journal papers, literature reviews, conference abstracts, and all studies published before 2009. Research papers focusing only on underground mining or processing plant optimization studies will also be excluded.

## 2.2. Information sources

The bibliographical search will be carried out using mining subject headings and text words related to open pit mining optimization methods in different engineering databases. Scopus, Web of Knowledge (Inspec and Web of Science), Elsevier (Science Direct), Directory of Open Access (DOAJ), IEEE Xplore, and Geological Society of America (GSA) electronic databases will be searched. Those databases will be accessed via University of Porto libraries.

## 2.3. Search strategy

Each database will be searched by article title, abstract, and keywords, using two groups of text words. The first group includes “Open pit”, “Surface min*”, “Open cast”, “strip min*”, mountaintop, and “Min* Exploitation” and the second group includes “Optimization”, “Lerch Grossman”, “Push & Relabel”, and “Ant colony”. Each keyword of the first group will be combined with the second group using the Boolean operator AND.

The defined combinations to execute the search are:

1. “Open pit” AND (Optimization OR “Lerch Grossman” OR “Push & Relabel” OR “Ant Colony”);
2. “Surface mining” AND (Optimization OR “Lerch Grossman” OR “Push & Relabel” OR “Ant Colony”);
3. “Open cast” AND (Optimization OR “Lerch Grossman” OR “Push & Relabel” OR “Ant Colony”);
4. “Min*Exploitation” AND (Optimization OR “Lerch Grossman” OR “Push & Relabel” OR “Ant Colony”);
5. “strip min*” AND (Optimization OR “Lerch Grossman” OR “Push & Relabel” OR “Ant Colony”);
6. mountaintop AND (Optimization OR “Lerch Grossman” OR “Push & Relabel” OR “Ant Colony”);

For better consistency, other keywords can be defined using other mining optimization methods or using the addressed problem of the found methods. To reduce searching time and records number, the preselected studies will be screened before being stored.

The records’ number will be automatically processed in an Excel spreadsheet Table 1 (appendix), considering the following criteria: date (≥2009), article type (article or article in press), article source type (journal), language (English), and topic. After that, the selected studies will be checked to identify further keywords that can be combined with the first ones, and be used for a second search. This search strategy will be repeated by two independent authors until no more relevant information can be found. Finally, to ensure all relevant literature, the reference lists of the included studies or relevant reviews identified through the search will also be screened. The new relevant studies will be added to the included papers and will be considered in the systematic review as articles from other sources. No grey literature sources will be used.

## 2.4. Study records

### *2.4.1 Data management*

After executing the search in the different databases, papers matching the criteria of the systematic review will be selected; their records will be stored in Mendeley for reference management and duplicates removal. After that, the full-text of the relevant records will be located, stored, and considered for assessment. Mendeley group and Google drive file will be used to share the collected records and the full-text articles, between the authors.

### *2.4.2 Selection process*

In the first step, the studies will be automatically filtered in the databases, using the eligibility criteria defined by the authors. Table 1 (Appendix) will be used to record the initial number of collected studies in each database as well as the excluded articles, both by automatic criteria and after analysis of the title and the abstract. Any study with potential doubts regarding its inclusion after reading the title and the abstract will be considered as relevant and will be included as well, although with a special mention to this fact. The full-text of all selected studies at this stage will be retrieved to assess their eligibility for inclusion in the systematic review. The

exclusion of any article after a full-text assessment will be recorded and justified in the final report. The data selection process will be reported and summarized through the PRISMA Statement flow diagram and a complementary text.

#### *2.4.3 Data collection process*

At this stage, the full-text articles defined to be included in the study will be screened and analyzed to extract the relevant data in each paper, to allow the authors to criticize and summarize the evidence of the results to achieve the research objectives. The extracted data will be collected and summarized by the first author in an Excel spreadsheet developed by the research team, and will be checked and verified by the second author. Any disagreement on the results will be solved by a discussion between two authors, and a third author will be involved to solve any further disagreement.

### 2.5. Data items

The data will be extracted to a table containing descriptive variables of each included study (the authors' names, publication year, main objective, methodology, results, conclusions, and future recommendations). In order to answer the research questions and objectives, the following items will be considered:

1. Characteristics of participants: open pit with or without underground, pit (depth, length and width), the minimum absolute elevation of the pit bottom, ore deposit, geological structure, mine production, exploitation method, main equipment used in mine, bench high, platform length, block size, ore/waste ratio, geological constraints, waste dump, environmental recovery, processing plant (in situ or not, distance from the mine), type of transportation system used, workers (number, professional categories, age, sex).
2. Type of intervention: optimization method, global or partial optimization and the software used.
3. Comparators: objectives, comparison with previous optimization procedure used or with the previous exploitation procedure for the same mine, comparison with other mines, geological hazards control, management system, and limitations.
4. Type of outcome measure: advantages (improvement in mine planning and safety in the long and short term), the effectiveness of implementation (cost and time).

The reviewers will report all the obtained variables. The authors will justify any added variables after the start of the review.

### 2.6. Outcomes and prioritisation

The primary outcome of this study is to identify the best optimization strategies applied to solve the main open pit mining problems (UPL and MBS), their objective function, implementation costs and time, referring to the software that can be used. The secondary outcome is the effectiveness of mine optimization in mine planning and mine safety. Finally, a comparison will be made based on the different objective functions and outcomes of the solutions of the optimization that will be found.

### 2.7. Risk of bias in individual studies

There is no prediction for conducting a risk of bias analysis in this study.

### 2.8. Data synthesis of the results

A quantitative synthesis is not appropriate to this study because of the results diversity. So, no meta-analysis is planned. If the results provide several interventions (optimization methods) and different outcomes measures, the methods will be classified by different groups. In case of missing data, the reviewers will contact the authors of the studies. If the data still cannot be obtained, authors will discuss to decide if the study will be included or excluded in the data collection process. In these cases, the studies will be identified. One or more qualitative narrative synthesis will be carried out to present and discuss the summarized extracted data, based on

the PRISMA Statement for reporting systematic reviews and meta-analysis (Liberati et al., 2009).

### 2.9. Meta-biases

It is not expected to carry out a meta-analysis in this study, due to the anticipated diversity of results.

### 2.10. Confidence in cumulative evidence

It is not expected to apply this parameter in the study.

### 2.11. Authors' contributions

Study design and development: RR, JD, JSB

Title/abstract screening: RR, JD

Full-text screening: RR

Data extraction: RR

Critical appraisal: RR, JD, JSB

Data analysis and interpretation: RR, JSB

Draft of the protocol: RR

Support in the draft of the protocol: JD, JSB

All authors read and approved the final version of the protocol.

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## Appendix

**Table 1.** Data Records

| Confirmation | 0 | Summary of excluded articles | | | | | | Databases | keyword Combination n° 1 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Summary of collected articles | Summary of selected articles | date | Article Type | Source type | Language | Off topic | Others (to be defined) | | nº of selected articles | total nº of collected articles | nº of articles after the introduction of exclusion criteria | | | | | |
| | | | | | | | | | | | date | Article Type | Source Type | Language | Off topic | Others (to be defined) |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Total | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Scopus | 0 | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Science Direct | 0 | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Inspec | 0 | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Open Access | 0 | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | IEEE | 0 | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | GSA | 0 | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | web of science | 0 | | | | | | | |