Different Time Scales of In-Pit Crushing and Conveying (IPCC) Enabled Open Pit Mine Planning: A Literature Review and Research Agenda

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ABSTRACT

In this paper the state-of-the-art open pit mine planning methods with In-Pit Crushing and Conveyor (IPCC) considering different time scales are reviewed. An overview is given on methods, regarding long and short-term mine planning, through a comprehensive literature review. The gaps and shortcomings of the current research are elaborated. Consequently, a specific research agenda on long and short-term mine planning with IPCC usage is stated. A research project aiming to contribute to the stated research problem is proposed. The results and observations of the literature review are discussed and evaluated. Suggestions are given for further research together with a comprehensive summary of the research findings.

1. Introduction

The demand for mineral resources is increased by a growing world population, economic growth in developing and emerging countries, and constant further innovation. The efficient planning of mining operations is vital to overcome the challenges of rising demand for mineral resources. In the face of rising fuel and labor costs, haulage is a massive part of the mining costs, representing approximately 40% [1]. Truck haulage also accounts for greenhouse gas and nitrogen oxide emissions [2,3].

In-Pit Crushing and Conveyor (IPCC) systems require accurate and detailed upfront planning. Due to the high capital costs of IPCC systems and the reduced flexibility in the mining operation and technical requirements such as the conveyor exit requirement, precise planning is crucial to guarantee a successful, economically viable operation [4].

IPCC is a haulage solution, which aims to reduce the costs of haulage and its emissions. Although the alternative usage of IPCC is widely discussed as a current trend in the mining industry [5], there are few coherent frameworks for strategic and short-term planning of IPCC [6, 7]. Currently, for example, cost estimations or mine plans with IPCC are only created based on case studies of single mining projects or based on estimates derived from empirical values [8]. These case studies are therefore not a general representative of the entire open pit mining industry. This paper aims to provide an overview of existing, related literature and to propose further research on mine planning with IPCC system.

To achieve this, some general background information about different IPCC systems is given. A structured review of the state-of-the-art open pit mine planning regarding IPCC is conducted to highlight varying long and short-term planning approaches and their relevance. Gaps and shortcomings in the current research are elaborated in Section 2. Afterward, a research agenda is

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stated that the author wants to realize in the future. Observations made during the literature review and while stating the to-be-solved research problem, are outlined. In Section 3, the results of the state-of-the-art mine planning methods and the proposal for further research are discussed. In conclusion, an outlook on further research potential is given and the findings are summarized.

2. State-of-the-Art

In the following, some general information and the classification of different IPCC systems is presented. Then, the various approaches for strategic and short-term mine planning with IPCC usage are reviewed. During the literature survey, the main objectives of long-term mine planning optimization with IPCC usage found in literature with a focus on crusher location optimization are outlined. Afterwards, research studies related to short-term mine planning with implementation of IPCC are presented.

An IPCC system is a continuous haulage system for surface mines. It consists of a crusher station or several crusher stations, which are located inside the pit. The crusher station(s) are operated in combination with a conveyor belt, which is used to transport the material out of the pit.

IPCC systems can be categorized based on their level of mobility into three categories: Fixed, semi-mobile, and fully mobile IPCC crusher systems [9]. Fully mobile crusher stations have built-in transport mechanisms such as crawlers, with which they can change their position following the mining face. Semi-mobile crusher stations have been located at one specific position for several years. Fixed crusher stations are located inside the pit and do not change their position [9].

2.1. IPCC in Strategic Open Pit Mine Planning

Long-term mine planning is considered as planning for several years to the whole mine life.

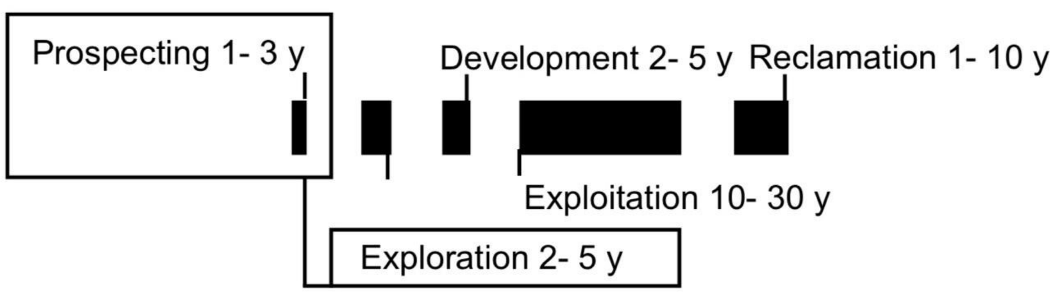

Figure 1 Stages of Mine Life (Time frames from [10])

Figure 1 depicts the stages of mine life as described by Hartmann, from prospecting to remediation. The long-term mine planning covers all time phases. Open pit mine planning with IPCC usage is important during the exploration phase and development phase. During the operation of the mine with IPCC other factors are important, which are mentioned in the short-term planning section. Before opening the mine with IPCC a detailed and socially approved closure and remediation concept needs to be planned. The usage of semi-mobile and fully mobile IPCC might hold special challenges for the remediation process because of the high amount of permanent steel structures and the major interventions into the landscape [11].

The objectives for the strategic mine planning with IPCC usage can be stated as production scheduling, location optimization, comparison to truck and shovel operations, and the optimization and assessment of various decision-making factors such as NPV.

Liu et al. [12] conducted a similar review of recent research agendas in Mining Equipment Management. Within this review, an overview is given about the current IPCC system and hybrid IPCC truck and shovel system management literature. In addition, research opportunities are pointed out. In addition to this review, four main objectives of long-term IPCC planning are summarized here with the focus on crusher location optimization.

Production scheduling optimization with IPCC usage – Few studies have been done on the production scheduling problem with IPCC usage. Production scheduling aims to find the best block extraction sequence for a mine that maximizes the net present value (NPV) and obeys certain technical and economic constraints. Technical constraints are for example geotechnical constraints such as the allowable slope angle. Economic constraints are for example commodity prices. To solve the problem a block model of discretized blocks of the modeled mineral deposit is created. To each block, an estimated tonnage and mineral grade is assigned [4, 13]. Then, mining blocks are clustered for the purpose of production sequencing. [14, 15, 16]

Long-term scheduling is composed of three steps: finding the optimal ultimate pit limit, pushback selection, and creation of production schedules [13].

In general, the techniques that can be used for production scheduling can be classified into: heuristic/metaheuristic algorithms and mixed-integer programming. To calculate an optimal solution within a reasonable time, approximation techniques should be applied [6].

Comparison of IPCC to truck and shovel system

Before developing a mining operation with IPCC usage during the feasibility study, a comparison can be done between truck and shovel equipment usage and IPCC system. Different methods are used to compare the technical feasibility and economic viability of the planned operation. One of them is discrete-event simulation. State-of-the-art studies of comparison of truck and shovel operations with IPCC operations through discrete-event simulation were for instance conducted by [17] and [18].

Optimize and access various decision-making factors regarding IPCC inauguration

It is not possible to evaluate the benefits and shortcomings of the IPCC inauguration without assessing various decision-making factors. To find out which factors are relevant, books, dissertations, journal articles and conference proceedings from 1988 to 2024 were reviewed. Each decisive factor was listed in a table. The results are presented in Table 1. Based on the reviewed literature, the most common and thus most relevant factors are economic factors such as NPV, CAPEX, and OPEX. These factors were mentioned most often within the reviewed literature. Some factors were considered neglected because of the number of occurrences in literature but considered important for the decision-making process. These factors include mostly environmental and social factors.

Table 1 Overview of decisive factors found in literature.

Category	Decisive factor	Count	Citations				
Economic	Operating Cost (OPEX)	10	[19]	[5]	[8]	[20	[21]
			[22]	[23]	[24]	[25]	[26]
	Capital Cost (CAPEX)	4	[19]	[8]	[24]	[5]	
	Economic Index (EcI)	1	[24]				

Category	Decisive factor	Count	Citations
	Net Present Value (NPV)	10	[27] [28] [19] [29] [30] [18] [5] [31] [30] [32]
	Other economic analysis, cost analysis, sensitivity analysis	7	[17] [33] [34] [8] [35] [36] [37]
Performance	Mine Life	3	[24] [18] [8]
	Mining Capacity	3	[28] [3] [9]
	Utilization	2	[9] [36]
	Availability	5	[38] [9] [18] [36] [39]
	Productivity	2	[38] [36]
	Mine Productivity Index (MPI)	2	[40] [41]
	Resource Recovery	1	[27]
	Major shortcomings of truck usage*	1	[8]
Environmental	Pollutants	5	[3] [38] [19] [2] [42]
	Energy consumption	2	[43] [44]
	Life Cycle Assessment (LCA)	3	[3] [45] [46]
	Other environmental study	6	[47] [23] [48] [49] [50] [51]
Social	Safety	3	[52] [5] [23]
	Other social concerns	1	[52]

*Major mine specific shortcomings of truck usage for instance insufficient climatic conditions for road conditions, dust, wash holes, etc. ** The methodology used to create this table is presented in [53]. The table was updated after this publication.

Crusher location optimization:

Most of the research on semi-mobile IPCC system optimization has been focused on the optimal position of the crusher in the pit. The objective of the operations research approach is to minimize the total transportation and associated costs by selecting the optimal location from a given set of potential crusher sites [6, 29]. These studies can be static or time-dependent. Other methods of solving the crusher location and relocation problem are for example simulation and heuristic algorithms. Another task is the optimization of the conveyor location.

Table 2 Overview of crusher location optimization studies.

Summary of approach	Shortcomings
Konak et al. [54] evaluated the selection of an optimal crusher location. The study is for an aggregate production quarry in Turkey. The decision was made based on the haulage distance. Both stationary and semi-mobile crushers were analyzed. An algorithm was developed to calculate the average haulage distance to the crusher from the mine. Up to three relocations during the mine life were considered.	The only decision variable considered is the haulage distance. Capital or relocation costs for the in-pit crusher are not included, this impacts the cost savings shown by the study [54].
Taheri et al. [55] used a simple approach to determine the optimum location of stationary crushers in deep open pit mines. The NPV of the haulage and installation costs is calculated for three candidate locations by the model. Then the location with the lowest costs is selected.	The model does not account for uncertainties in costs caused by crusher breakdowns or shovel downtimes. Candidate locations are selected randomly [55].
Rahmanpour et al. [56] studied the optimal in-pit crusher location selection as a trans-shipment problem with single hubs. An analytical hierarchical process was used to select candidate locations. Six economic and eleven technical factors were considered. The Hub-spoke network connected all destinations to source locations to increase haulage capacity.	No delays and queuing during trans-shipment at hubs were considered [56].
Roumpos et al. [57] suggested an iterative model to minimize the total transportation cost of continuous surface mines. The best location for a belt conveyor distribution point is found using simulation.	The model is only valid for continuous operating surface mines. Only operating and capital costs are considered, operational uncertainties such as conveyor downtime are not considered [57].
Paricheh et al. [58] developed a heuristic model in 2018 to hierarchically find the optimum in-pit crusher locations in open pit mines and the optimal relocation moment. The crusher location is optimized by an iterative, linear dynamic facility location model which minimizes the cost of haulage. The relocation moment of the crusher is optimized by maximizing the discounted cash flow throughout the life of mine.	Strictly deterministic model [58].
Summary of approach	Shortcomings
In 2017 Paricheh et al [59] proposed another model modeling the location problem dynamic based on primary factors like the	A strictly deterministic model with a hypothetical case study [59].

haulage distance. The objective of the model was to minimize the haulage costs.	
Paricheh and Osanloo [60] used a stochastic facility location model in 2016 to find the optimal crusher location in open pit mines. Production and haulage cost uncertainty was considered. The model was formulated as a P-median problem.	The model does not work well in all cases [60].
Paricheh and Osanloo [61] developed a search algorithm in 2019 to find the optimal crusher locations from a set of candidate locations. The optimal candidate locations are practical and cost-effective. Six specific rules were used in addition to conventional rules based on topography and ramp intersection as well as block aggregation policies. The number of candidate locations in a case study of the Sungun mine in Iran could be reduced from 283 to 23.	No geotechnical or shape restrictions are considered when defining candidate locations [61].

Some of the Disadvantages of current crusher location optimization models include [62]:

- The mine plan and sequencing of mining are not considered for the location optimization. Therefore, economic optimization cannot be guaranteed in the long term.
- The case study results of Kamrani [6] are unreliable due to hypothetical mine data with simplified geometrical assumptions.
- Most models choose locations without taking a real road network into account.
- Geometric IPCC design parameters must be considered.

IPCC in Short-Term Open-Pit Mine Planning

In this section, the different approaches for Short-term planning are reviewed. Short-term planning is referred to as a term for planning operations with a period of weeks to several months. Operational planning is the task of allocating short-term plans to day-to-day mining operations. Objectives of the short-term planning are to synchronize the long-term production plan by generating feasible short-term production schedules. Short-term schedules need to account for the effects of the IPCC location such as effective production capacity and haulage distance. In addition, the location(s) of the hauling equipment(s) need to be planned to ensure product quality (grade blending) and quantity for the mine to be profitable and produce an ore concentrate [7,62,63, 64, 65].

Short-term to mid-term planning is about both operation and downtime scheduling. Maintenance scheduling and timed replacement of loading, hauling, and crushing equipment is as important as production quantity and grade control. Geotechnical and environmental circumstances influence the mid-term mine design.

This section covered information about production scheduling, location optimization, comparison to truck and shovel operations, and the optimization and assessment of various decision-making factors. Through this, some general information about IPCC planning was presented.

3. Statement of Research Agenda

The author proposes a research methodology for further research on short and long-term mine planning with IPCC usage. For the statement of this research problem, the research questions are: 1) How can short-term mine planning with IPCC usage be optimized and simulated? and 2) How can the optimal crusher locations for a semi-mobile IPCC be chosen? The objective of the research is to create a comprehensive tool for short-term production planning and analysis options for semi-mobile IPCC usage. In addition, the long-term mine plan must be fulfilled by the optimal chosen crusher locations. The creation of a separate mathematical optimization tool is a second objective. The underlying model needs to be pragmatic and able to capture uncertainties. In the future, the grade of detail and properties of the model must be defined. For example, about the operational constraints, requirements, and costs, associated with implementing the IPCC system. A comprehensive research methodology must be determined before creating a model that can consider operational uncertainty. For the determination of the optimal crusher location, uncertainties might be neglectable.

A mathematical optimization algorithm is designed to optimize the long-term crusher locations. The Scope of the Optimization Model experimental design to optimize the crusher locations:

- Collection and analysis of data
- Establishment of a road network and block model sequenced into mining cuts to generate insight into the tabular oilsands deposit.
- Development of a mathematical formulation and framework for the crusher location optimization. Improvements to existing research work are discovered and existing work is adjusted based on industry needs. For example, the bench height for crusher panels must be based on technically specified crusher heights [6].
- Development, training, testing, and validation of an effective optimization model for optimized crusher location calculation [23].

Discrete Event Simulation is chosen to optimize the short-term mine haulage management. Before the designing of the simulation model, the scope and objective of each analysis needs to be defined [28]. Successful performance of discrete event simulation includes quality control procedures. Important are verification (a check whether the simulation model works as intended) and validation (a check whether the simulation model reflects the real system sufficiently) [66].

In the following research study, the next step is the statistical analysis of input data for the simulation model. An action plan formulation is a detailed plan outlining the actions needed to reach the defined goals for IPCC scheduling and haulage simulation. The action plan is a sequence of steps that must be performed for the model to succeed. Next a model, a depiction of the real mine must be defined. The model must be verified and tested. After the creation of the underlying model, it can be implemented into suitable simulation software. With the simulations, scenarios are performed to solve the defined analysis questions. The results of these simulations need to be validated.

The main steps of developing and implementing a simulation framework include:

- Statistical analysis of input data for the model
- Action planning
- Developing the model (as a prototype program or in a simulation software)
- Model verification and simulation validation.
- Running of scenarios, to solve defined analysis questions

<u>Suggestions to consider in future research:</u>

Further research should focus on the systematic reporting of benchmarking parameters of IPCC operations and the implementation of the described neglected decisive factors into calculation or simulation models. Such neglected factors include but are not limited to: safety indexes, lifecycle assessments, and other environmental analyses like studies about the decrease of energy consumption or emissions. Especially analyzing and considering data from smaller IPCC operations is relevant for the future, successful implementation of the technique in the industry. Each mining company should have its own confidential record of historical data and is obligated by law and order to keep records to have an official permit to operate. These records should be made available for research. Different stakeholders must engage and cooperate to strengthen rural and central governance in the mineral sector to increase awareness about sustainable decision factors. A modern research approach should capture uncertainty in mining equipment management.

4. Observations and Discussions

The results obtained from the review of the state-of-the-art mine planning methods for IPCC and the proposal for further research are discussed here. Today, the relevance of the economic decisive factors is significant. Other factors like social life cycle analysis are often neglected when considering how seldom they were mentioned in the latest literature. Economic factors are important for the success of the IPCC inauguration, but other factors like performance, environmental, and social factors should not be neglected during decision making. The neglect of these factors leads to a lack of knowledge about both the decisive factors of IPCC and its constraints regarding long-term mine planning.

The scope of the research problem is vague. The exact research methodology must be explained in more detail. Ethical approval is an important lack of the research proposal. Input data from a real mine must be collected to be able to start the proposed research.

5. Conclusion

A comprehensive literature review about open pit mine planning with In-Pit Crushing and Conveying usage is outlined. Different time scales of mine planning are analyzed. Strategic open-pit planning is planning with a time span of several years to the whole mine life. There are some main objectives of long-term IPCC planning. These objectives include the optimization of the production schedule, the selection of the best crusher location and relocation position in the mine layout, and the comparison of the economic and technical feasibility of truck and shovel and IPCC usage when conducting the feasibility study and technical mine planning.

In comparison to long-term, short-term planning is referred to as a term for planning operations with a period of weeks to several months. Short-term mine schedules need to account for the effects of the current IPCC location such as effective production capacity and haulage distance. In addition, the location(s) of the hauling equipment(s) need to be planned to ensure product quality (grade blending) and quantity for the mine to be profitable and produce an ore concentrate with constant chemical properties.

After the literature review, a research agenda is described. The statement describes the approach of performing a scenario analysis to answer questions about the ideal design of an IPCC system before the inauguration of this haulage method at a mine site. The scenario analysis, with Discrete Event Simulation, is a decision-making tool helping to quantify capacities, layout, and type of IPCC equipment. In this section, the basic methodology and procedure of action for the realization of this planning approach are outlined. In addition, the methodology to create an effective optimization model for the calculation of the optimal semi-mobile crusher location is described. The methodology includes a case study within a tabular oil sand deposit.

In future research, input data from a real mine must be collected to be able to start the proposed research. Additionally, increased consideration of the described neglected decisive factors in calculations or simulation models is important.

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