# Decisive Factors and Constraints of In-Pit Crushing and Conveying (IPCC) Regarding Long-Term Mine Planning

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## ABSTRACT

*Different In Pit Crushing and Conveyor (IPCC) systems, their usage, benefits and functionality are outlined and compared. An overview is given on decision-making factors regarding the inauguration of IPCC in long-term mine planning. In addition, real world technical constraints of IPCC are identified through a comprehensive literature review. Suggestions are given for further research and the implementation of the decisive factors in decision making tools. An outlook on the implementation of decisive factors and constraints in current and future simulation and optimization tools regarding strategic mine planning is presented.*


## 1. Introduction

The demand for sustainably mined raw materials is constantly rising. The world's population reached 8 billion people in 2022, and the demand for raw materials is growing with the world's population. Meeting this demand will represent a challenge, as the ore deposits are getting deeper and have lower grades. Thus, deposits are becoming more complex to mine. Moreover, the fuel and labor costs are continuously rising. To answer the climate crisis, more energy-efficient and sustainable mining solutions are required. Haulage is a major part of the mining costs, it represents approximately 50-60 %. Haulage also accounts for a lot of emissions.

In Pit Crushing and Conveyor (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, there is no coherent framework for the inauguration of IPCC. Which decision-making factors need to be analyzed when considering to implement IPCC? What are the constraints of the IPCC usage? Or in short, under which circumstances is it not feasible or thoughtful to use IPCC? Here, a comprehensive overview of decisive factors and constraints of IPCC usage found in the current literature is provided.

Currently decisive factors are only utilized based on case studies of single mining projects. These research data are therefore not in general representative for the entire surface mining industry. This paper aims to close this literature gap and to provide recommendations for further research on this topic. To achieve this, some general background information is given about different IPCC systems. Shortcomings and benefits of IPCC are compared. A structured, standardized review of the current literature is conducted to find out decisive factors and their relevance. All of the previously found decisive factors are listed and the usage is counted to evaluate the relevance of each factor. In a second step, constraints of IPCC usage are outlined and discussed. In conclusion an outlook on further research potential is given and the findings are summarized.

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## 2. General Information

Some background information about In-Pit Crushing and Conveyor (IPCC) systems is presented in the following. The three different types: Fully-mobile, Semi-mobile and Fixed IPCC are explained. A review of the current industry IPCC usage and current industry trends are referenced. The IPCC system is compared with truck haulage, the resulting benefits and shortcomings are listed.

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 of 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.

Figure 1 shows the process flow of the IPCC system, which is a bulk material handling system that includes a feed system, crusher stations(s), a conveyor belt and a discharge system. (Ritter, 2016) P.8

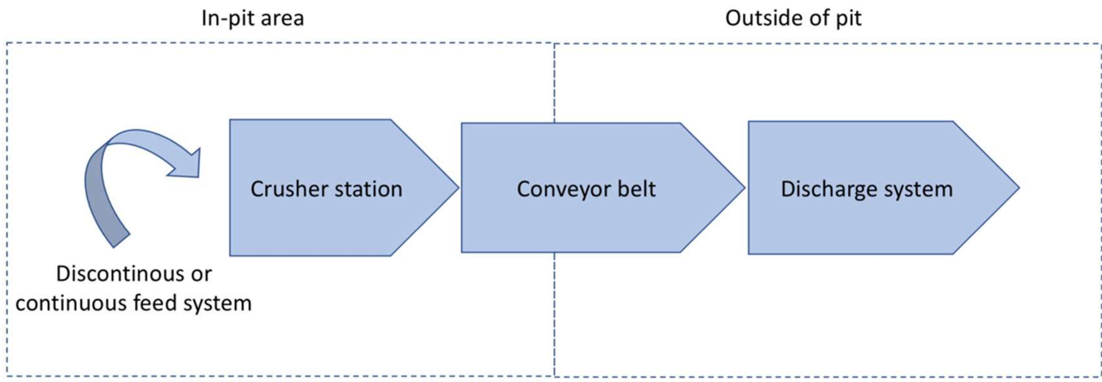


Figure 1 IPCC process flow chart based on (Ritter, 2016) P. 8

IPCC systems can be categorized based on their level of mobility into the three categories: Fixed, Semi-mobile and Fully mobile IPCC crusher systems. 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 are located at one specific position for several years. Fixed crusher stations are located inside the pit and do not change their position. (Ritter, 2016) P.8 et seq.

An industry overview is for example given by (Ritter, 2016). Other studies focused on specific countries or industry sections, for example (Braun, 2019) focused on quarries in Germany. To gain an overview of current trends in the IPCC usage, refer to current journal articles like (Leonida, 2019), (Al Habib et al., 2022), (Noriega & Pourrahimian, 2022) or (a Carter, 2010).

Benefits of IPCC include, but are not limited to:

- Less local emissions like dust, noise, $NO_x$ emissions, $CO_2$ emissions
- Less deadweight transportation
- In most cases, reduced operating costs like labor costs, fuel costs
- Reduced safety risks
- Conveyor belts are able to cross obstructions
- Continuous and predictable operation due to continuous flow of material and long-term mine planning, process is easy to simulate which allows a flexible relocation analysis
- Notable reduction in road maintenance costs (Utley, 2011) P.909

There are some general, main shortcomings of IPCC compared to haul truck usage:

- The mine planning is not flexible. For instance, it is not possible to easily change the location of a conveyor belt or increase/decrease its capacity.
- High capital costs have to be paid beforehand
- Availability and reliability of the IPCC system is essential. There might be a shortage of repair parts in remote areas. Foresighted maintenance must be done. If only one component fails with unplanned downtime, the whole production stream is not utilizable. If these problems are not fixed, this might result in failure to meet the targeted production capacity.
- The material loaded must fulfill certain conditions to be crushable and transportable with the conveyor belt. Some properties are obvious, for example the lump size. Others like the clay content and the associated adhesive strength are not obvious.

  (Utley, 2011) P.909
- Few benchmarks of IPCC projects exist, especially for smaller operations it is difficult to obtain reference data
- IPCC systems are difficult to test before an inauguration decision is made

  (Braun, 2019) P.3 (Leonida, 2019)

Through this, some general information about IPCC was presented. Additional information sources for an industry overview, which is not scope of this work were given. Lastly, IPCC system usage was compared to the truck and shovel usage.

## 3. Decisive Factors

Considering the shortcomings and benefits of IPCC usage, it is not possible to draw a general conclusion about the usage of IPCC at a specific mine site or not. Therefore, other decisive factors need to be considered. To find out which factors are relevant, current books, dissertations, journal articles and conference proceedings were reviewed. Each decisive factor was listed in a table together with the reference to the source in the appendix. The relevance of each factor was evaluated.

The results are presented in Table 1. The most common and thus most relevant factors are explained below. Some factors were considered as neglected because of the number of occurrences in literature but considered important for the decision-making process. These factors are outlined without a relevance statement and discussed further along with the other results.

Table 1 Resulting overview of decisive factors found in current literature

| Category | Decisive factor | Count | Relevance |
|---|---|---|---|
| Economic | Operating Cost (OPEX) | 4 | Medium |
| | Capital Cost (CAPEX) | 4 | Medium |
| | Economic Index (EcI) | 1 | Low |
| | Net Present Value (NPV) | 7 | High |
| Category | Decisive factor | Count | Relevance |

| | | | |
|---|---|---|---|
| | Other economic analysis, cost analysis, sensitivity analysis | 5 | High |
| Performance | Mine Life | 3 | - |
| | Mining Capacity | 3 | - |
| | Utilization | 1 | - |
| | Availability | 3 | - |
| | Productivity | 1 | - |
| | Mine Productivity Index (MPI) | 2 | - |
| | Resource Recovery | 1 | - |
| | Major shortcomings of truck usage* | 1 | - |
| Environmental | Pollutants | 3 | - |
| | Life Cycle Assessment (LCA) | 2 | - |
| | Other environmental study | 1 | - |
| Social | Safety | 1 | - |
| | Other social concerns | 1 | - |

*Major mine specific shortcoming of truck usage for instance insufficient climatic conditions for road conditions, dust, wash holes etc.

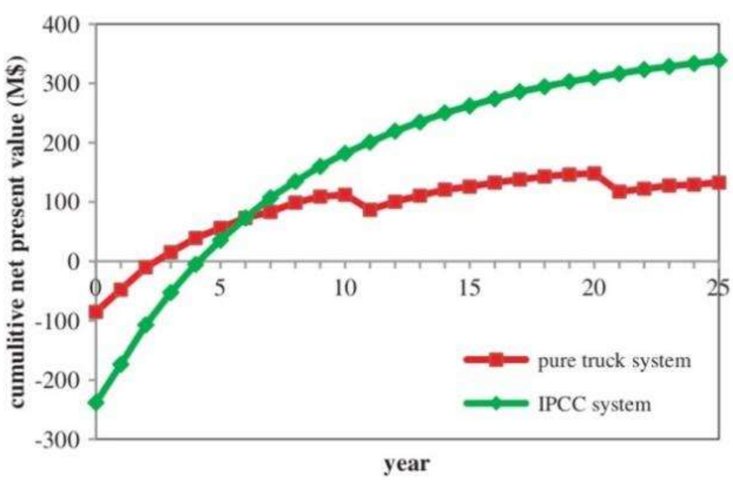


Figure 2 Graph showing the comparison of NPV for IPCC system and truck and shovel adopted from (Osanloo & Paricheh, 2019) P. 436

Figure 2 is a graph showing the typical comparison of NPV, or discounted cumulative yearly cash flow for both the operation of the IPCC system and the truck and shovel system. The IPCC system must be replaced after 20 – 25 years whereas trucks require major replacement and maintenance after approximately seven to ten years of operation. This is a common example of the usage of decisive factors to evaluate IPCC systems in long-term mine planning. In practice, the long-term mine plan needs to include an optimal IPCC location and relocation plan in addition to the financial analysis. (Osanloo & Paricheh, 2019) P. 436, (Moradi-Afrapoli & Askari-Nasab, 2022) P.199

This section gave a coherent overview about decision-making factors regarding long-term mine planning. The major result, the importance of the NPV was analyzed and explained with an example.

## 4. Constraints of IPCC Usage

While constraints of IPCC usage seem to be similar to IPCC shortcomings and there might be some overlaps, the two topics are not totally similar. In this section it is asked under which circumstances it is not feasible or useful to inaugurate IPCC into a new or running operation. It is important to distinguish between technical and economical IPCC usage constraints, while each of them can be equally important. Both categories are presented here. The mentioned constraints are analyzed and discussed.

Some major economic constraints are presented here:

- One of the major economic constraints is the necessity to invest a high amount of **upfront capital costs**. (Utley, 2011) P.943
- The **flexibility** of the operation has decreased drastically**.** For example, it is not feasible to increase or decrease the capacity of the IPCC system whereas an additional truck is easily bought. (Osanloo & Paricheh, 2019) P. 452
- IPCC is most effective if used for **long haulage distances**, to transport **high tonnage** and used over a **long mine life**. Smaller operations are mostly unable to meet these constraints. (Mohammadi & Moosakazemi, 2011) P.11
- Predictive maintenance is necessary to overcome unplanned downtime. Maintenance and other **downtime** limit the production time and economic viability of the operation. (Morrison, 2017)
- **Limited knowledge** and the non-availability of benchmarks of similar projects makes it difficult to assess the performance of IPCC systems before implementing them. There is a high economic risk when implementing IPCC especially for smaller operations mainly because the system cannot be tested easily and of these lacks of information. (Braun, 2019) P.2

Some major technical constraints are listed below:

- The availability of a **stable electric grid** is a requirement for the successful implementation of an IPCC system. (Braun, 2019) P.2
- Often not considered but important is the **configuration of the loaded material**. Its coarseness, load ability, water content, abrasiveness or the content of sticky clays etc. can determine the success of an IPCC operation. (Utley, 2011) P. 944
- The **angle of the conveyor belt** is a limitation if a traditional conveyor belt is used. For high angle conveyors the additional cost of these alternative conveyor systems and eventual throughput limitations must be considered. (Osanloo & Paricheh, 2019) P.452
- Ideally **unconsolidated** or easy to extract **rock** makes an IPCC inauguration feasible (Braun, 2019) P.2

These constraints have changed in recent years with the technical progress. While technical restrictions are overcome, precise planning is still essential for the operation. (b Carter, 2015) P.42

For example the usage of high angle conveyors has become more common. A case study about the usage of a high angle conveyor can be found from (dos Santos & Stanisic, 1986).

## 5. Discussion of Results

The results obtained from the systematic review of the current literature and the search for decisive factors are discussed here. The relevance of the economic decisive factors are significant. Other factors like social life cycle analysis can be considered neglected, when considering how seldom they were mentioned in the latest literature. Economic factors are definitely important for the success of the IPCC inauguration but other factors like performance, environmental and social factors should not be neglected when making a decision.

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. This is the major shortcoming of the state-of-the-art approaches to decision-making and IPCC planning.

## 6. Conclusion

This review has covered a wide range of thirty studies to determine the major decisive factors of IPCC systems regarding long-term mine planning. In addition to the analysis of decisive factors, technical and economical constraints are categorized and summarized. The discussion of the results shows that many important decisive factors are neglected in the latest literature. It also shows the importance of economic factors such as the NPV. While this economic factor is without question important, other performance, economic, environmental and social factors are sparsely found in literature.

Some recommendations for further research are the systematic reporting of benchmarking parameters of existing IPCC operations to provide more data for the decision-making process in long-term mine planning. In addition, more modeling and subsequent simulations should be conducted, which overcomes the shortcoming of the lack of testability of IPCC systems.

Economic, performance, environmental and social decisive factors should be analyzed before deciding about the implementation of an IPCC system in a long-term mine plan. There are technical and economical constraints for the IPCC usage. Some of these constraints are often overlooked in long-term mine planning while others like the high upfront capital costs are more obvious. The technical constraints range from the configuration of the loaded material among others to the stability of the electric grid. The technical constraints can be overcome with technical progress, whereas precise planning stays crucial to overcome the economic constraints.

## 7. Suggestions and Future Research

An outlook on the implementation of decisive factors and constraints of the currently existing and future simulation and optimization tools regarding strategic mine planning is presented. Some approaches model the IPCC system mathematically for example with a system dynamics model (Abbaspour & Drebenstedt, 2019). Such models can be used to model the transition time from a truck and shovel operation to an IPCC operation. Other innovative approaches focus on simulation techniques such as discrete-event simulation. Unlike mathematical modeling discrete event simulation can be used to model dynamic processes. These tools can be used to study models that are discrete, dynamic and stochastic. The accessed decisive factors can be input parameters for future discrete event simulation models. With the help of such models, what-if scenarios can be created, to decide about the best possible IPCC operation. State of the art studies of comparison of truck and shovel operations with IPCC operations through discrete-event simulation were for instance conducted by (Bernardi, Kumral, & Renaud, 2020) and (Villeneuve, Ben-awuah, & Vasquez-Coronado, 2020).

Further research should focus on the systematic reporting of benchmarking parameters of IPCC operations and the implementation of the accessed decisive factors into calculation or simulation models. Data of smaller IPCC operations is especially relevant for the future, successful implementation of the technique in the industry.

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# 9. Appendix

## 9.1. List of Abbreviations

Table 2 List of abbreviations used in the paper.

| Term | Abbreviation |
|---|---|
| Capital Costs | CAPEX |
| Economic Index | EcI |
| In-pit crushing and conveying | IPCC |
| Life cycle assessment | LCA |
| Mine Productivity Index | MPI |
| Net present value | NPV |
| Operating Costs | OPEX |

## 9.2. Detailed overview of results

Table 3 Resulting overview of decisive factors found in current literature.

| References | Method of IPCC | Category | Decisive factor | Mentioned in number of papers |
|---|---|---|---|---|
| (Nunes, Delboni, de Tomi, Infante, & Allan, 2019),<br>(Abbaspour & Drebenstedt, 2019)<br>(Leonida, 2019)<br>(Mohammadi & Moosakazemi, 2011)<br>(b Carter, 2015)<br>(c Carter, 2022)<br>(Radlowski, 1988) | | Economic | OPEX | 7 |
| (Nunes, Delboni, de Tomi, Infante, & Allan, 2019),<br>(Abbaspour & Drebenstedt, 2019)<br>(Leonida, 2019)<br>(Mohammadi & Moosakazemi, 2011) | | | CAPEX | 4 |
| (Abbaspour & Drebenstedt, 2019) | | | EcI | 1 |
| References | Method of IPCC | Category | Decisive factor | Mentioned in number of papers |

| | | | | |
|---|---|---|---|---|
| (Nehring, Knights, Kizil, & Hay, 2018),<br>(Samavati, Essam, Nehring, & Sarker, 2020),<br>(Nunes, Delboni, de Tomi, Infante, & Allan, 2019)<br>(Liu, Dingbang, & Pourrahimian, 2021)<br>(Paricheh & Osanloo, 2020)<br>(Villeneuve, Ben-awuah, & Vasquez-Coronado, 2020)<br>(Leonida, 2019)<br>(Shamsi, Pourrahimian, & Rahmanpour, 2022)<br>(Radlowski, 1988) | Semi-mobile, Fully mobile | | NPV | 9 |
| (Bernardi, Kumral, & Renaud, 2020)<br>(Osanloo & Paricheh, 2019)<br>(Topf, 2017)<br>(Mohammadi & Moosakazemi, 2011)<br>(Mikhailov, Garmaev, Garifullin, & Kazakov, 2019)<br>(Morrison, 2017) | Fixed/mobile<br>Fully mobile | | Other economic analysis, cost analysis, sensitivity analysis | 6 |
| (Abbaspour & Drebenstedt, 2019)<br>(Villeneuve, Ben-awuah, & Vasquez-Coronado, 2020)<br>(Mohammadi & Moosakazemi, 2011) | Semi-mobile | Performance | Mine Life | 3 |
| References | Method of IPCC | Category | Decisive factor | Mentioned in number of papers |
| (Samavati, Essam, Nehring, & Sarker, 2020) | | | Mining Capacity | 3 |

| | | | | |
|---|---|---|---|---|
| (Norgate & Haque, 2013),<br>(Ritter, 2016) | | | | |
| (Ritter, 2016)<br>(Morrison, 2017) | | | Utilization | 2 |
| (Sousa, et al., 2022),<br>(Ritter, 2016)<br>(Villeneuve, Ben-awuah, & Vasquez-Coronado, 2020)<br>(Morrison, 2017) | | | Availability | 4 |
| (Sousa, et al., 2022)<br>(Morrison, 2017) | | | Productivity | 2 |
| (Wachira, 2022)<br>(Wachira, Githiria, Onifade, Moshood, & Mauti, 2021) | | | Mine Productivity Index (MPI) | 2 |
| (Nehring, Knights, Kizil, & Hay, 2018) | Semi-mobile,Fully mobile | | Resource Recovery | 1 |
| (Mohammadi & Moosakazemi, 2011) | | | Major shortcomings of truck usage* | 1 |
| References | Method of IPCC | Category | Decisive factor | Mentioned in number of papers |
| (Norgate & Haque, 2013)<br>(Sousa, et al., 2022),<br>(Nunes, Delboni, de Tomi, Infante, & Allan, 2019) | | Environmental | Pollutants | 3 |

| | | | | |
|---|---|---|---|---|
| (Norgate & Haque, 2013)<br>(Abdollahi, Aghayarloo, Afrapoli-Moradi, & Askari-Nasab, 2020) | | | LCA | 2 |
| (Braun, 2019)<br>(b Carter, 2015) | | | Other environmental study | 2 |
| (Abbaspour, Drebenstedt, & Dindarloo, 2018)<br>(Leonida, 2019)<br>(b Carter, 2015) | | Social | Safety | 3 |
| (Abbaspour, Drebenstedt, & Dindarloo, 2018) | Fixed, Semi, Fully | | Other social concerns | 1 |