Mining Equipment Management

Subjects: Engineering, Industrial | Mining & Mineral Processing | Computer Science, Interdisciplinary Applications
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Mining sector is an economic foundation and the main source of national wealth for many countries. Modern mining operations are ever more reliant on efficient usage of costly large-scale mining equipment (e.g., trucks, shovels/excavators/loaders, conveyors and crushers). Thus, mining equipment management is becoming crucial for the mining industry. To be viable and sustainable, mining enterprises need to operate different types of mining equipment units at various stages with the objective of minimizing the total cost or maximizing the whole productivity.

Keywords: open-pit mining ; mining equipment management ; shovel–truck

1. Introduction

Nowadays, with the rapid development of modern mining technology, semi-automated or automated machinery and equipment have been widely applied in a variety of mine sites around the world. A contemporary mine site typically lasts from many years to several decades, continually providing metallic ores that are important raw materials for the manufacturing industry or non-metallic ores that are also vital to other industries such as construction, agriculture and chemical industries. For mineral-rich countries (e.g., Australia, Canada, Russia, Chile, Iran), the mining sector creates millions of jobs and substantial export earnings which are sources of national wealth to drive the development of other economic sectors such as education, transportation and commerce. On the other hand, mining exploration and exploitation require a large capital investment and involve huge annual cash flows. Therefore, many researchers have studied different kinds of mining optimisation problems from different perspectives to maximize the value of the whole mining process under constraints such as resource capacity, precedence, extraction, haulage, crushing, grade control, stockpiling, railing, shipment, environmental protection and economic issues. Among these studies in mining optimisation, some were devoted to modelling the ultimate mine design and long-term strategic planning problems over the life of a mine (with the time horizon of 10–30 years, typically); the majority of works focused on open-pit mine block sequencing problems at the tactical level (with the time horizons measured in months); some focus on short-term mine equipment planning and scheduling problems (with time windows measured in weeks) at the operational level.

2. Shovel–Truck (ST) System

In open-pit mining, shovels (excavators) and trucks are the most widely used equipment, because material handling (mainly excavation with haulage) is the most important mining operation. According to previous studies, material handling accounts for nearly 50% of the total operating cost in most open-pit mines. In addition, excavation and haulage operations are highly interdependent and inter-reliant. Usually, a fleet of mining trucks is compatibly matched with a large shovel; and the productivity (e.g., reducing the total idle time) of one shovel must rely on the truck fleet management (e.g., optimising the cyclic queuing times of a truck fleet). For better understanding, the main components and operation processes of the ST system are illustrated in **Figure 1**.

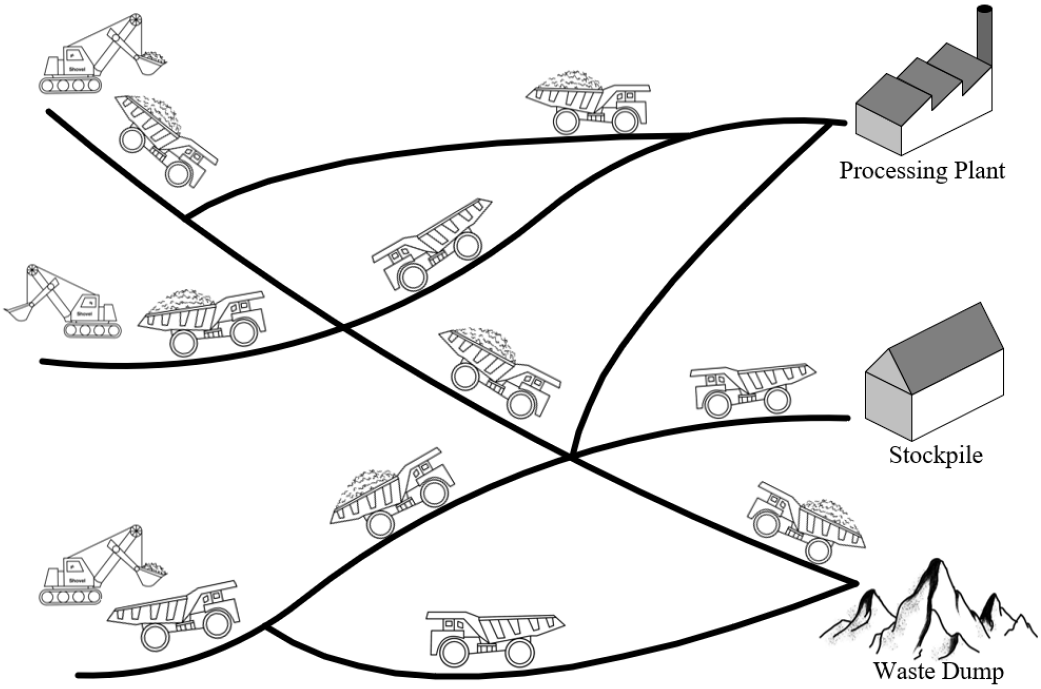

Figure 1. Illustration of main components and operation process of the ST system.

Table 1 summarises the main characteristics of recent papers on the ST system in terms of the scholars, publication year, journals, country of the first author, problem types and solution techniques. As shown in **Table 1**, some findings are given as follows. First, most research considered the mixture of shovels and trucks, e.g., determining the best matching factor; selection with sizing of trucks and shovels; dispatching a fleet of trucks to one shovel. In comparison, investigation of individual shovel or truck management system is rare relatively. Second, most of studies on the ST system belong to a kind of the planning-type optimisation problems such as the ST allocation/dispatching/assignment/matching problem. In contrast, few studies focused on more complicated scheduling-type problem based on the application of classical machine scheduling theory. Note that planning deals with the optimisation problems of resource capacity, facility design, equipment allocation and personnel deployment without considering timing factors. Scheduling is concerned with the efficient allocation of equipment units to jobs (operations) and sequencing the operations on each equipment unit with timing factors. For example, the parallel-machine scheduling with sequence-dependent set-up times was recently applied to a real-world mine excavators timetabling case [1]. Indeed, the dynamic vehicle routing problem could be applied to the routing optimisation of open-pit truck fleets [2][3]. Third, most solution techniques for the ST problems are mainly based on the formulation of MIP models with the use of exact MIP solvers. More efficient solution approaches, such as metaheuristic algorithms, which can efficiently solve large-scale instances, are relatively occasional. Finally, for scheduling (dispatching and sequencing) a fleet of trucks associated with a shovel, most existing mathematical programming models are relatively basic. To be more applicable in practice, the ST scheduling models should be extended by considering more actual requirements, such as the best matching factor, the selection of trucks/shovels, the layout of haulage roads, the queuing (e.g., waiting/idle times) of trucks in the scheduling process, and maintenance/failure of mining equipment, etc.

Table 1. Characteristics analysis of publications on the shovel–truck (ST) system [1][4][5][6][7][8][9][10][11][12][13][14][15][16][17][18][19][20][21][22][23][24][25][26][27][28][29][30][31][32].

Authors	Year	Country	Problem Types	Solution Techniques
Young and Rogers	**2022**	**USA**	**Mine haul truck dumping process simulation**	**A high-fidelity modelling method**
Liu et al.	**2022**	**China**	**Mine excavators timetabling**	**Mixed integer programming and metaheuristics**
de Carvalho and Dimitrakopoulos	**2021**	**Canada**	**Integrated truck-dispatching and production**	**Reinforcement learning**
Upadhyay et al.	**2021**	**Canada**	**Production scheduling with shovel allocation**	**Mixed integer programming**
Aguayo et al.	**2021**	**Chile**	**Productivity and safety of shovel–truck system**	**Interaction analysis**
Elijah et al.	**2021**	**Kenya**	**Shovel–truck haulage optimisation**	**Queuing theory**

Authors	Year	Country	Problem Types	Solution Techniques
Wang et al.	2021	China	Mine truck fuel consumption analysis	Regression analysis
Bakhtavar and Mahmoudi	2020	Iran	Shovel–truck allocation	Scenario-based robust optimisation
Basiri et al.	2020	Iran	Reliability assessment of shovel–truck system	Statistical methods
Zhang et al.	2020	China	Multi-objective unmanned truck scheduling	Improved genetic algorithms (NSGA-II)
Kansake and Frimpong	2020	USA	Estimate tire dynamic forces on haul roads	An analytical model
Shah and Rehman	2020	Pakistan	Shovel–truck allocation problem	Mixed integer programming
Ozdemir and Kumral	2019	Canada	A two-stage shove-truck dispatching system	A simulation-based optimisation approach
Dabbagh and Bagherpour	2019	Iran	Matching factor of shovel–truck system	Ant colony optimisation
Liu and Chai	2019	China	Routing optimisation of open-pit trucks	Mixed integer programming
Moniri-Morad et al.	2019	Iran	Capacity analysis of shovel–truck system	Discrete event simulation
Sun et al.	2018	China	Prediction of travel times of trucks	Machine learning techniques
Baek and Choi	2017	Korea	Design of a haul road for an open-pit mine	Douglas–Peucker algorithm
Dindarloo and Siami-Irdemoosa	2017	USA	Classification and clustering of shovels failures	Data mining techniques
Patterson, Kozan and Hyland	2017	Australia	Energy efficient shovel–truck scheduling	Mixed integer programming and metaheuristics
Bajany et al.	2017	South Africa	Shove-truck dispatching	Mixed integer programming
Burt et al.	2016	Australia	Mining equipment selection	Mixed integer programming
Chang et al.	2015	China	Open-pit truck scheduling	Mixed integer programming
Dindarloo et al.	2015	USA	Truck and shovel selection and sizing	Stochastic simulation
Rodrigo et al.	2013	France	Dynamic open-pit mine truck allocation	Simulation-and-optimisation framework
Choi and Nieto	2011	Korea	Haulage routing optimisation of mining trucks	Least-cost path algorithm with Google Earth
Souza et al.	2010	Brazil	Dynamic truck allocation in open-pit mining	Hybrid metaheuristic algorithms
Topal and Ramazan	2010	Australia	Mine equipment maintenance scheduling	Mixed integer programming
Choi et al.	2009	Korea	Haulage routing optimisation of mining trucks	Multi-criteria least-cost path analysis
Ercelebi and Bascetin	2009	Türkiye	Shovel–truck dispatching	Linear programming and queuing theory

3. In-Pit Crushing–Conveying (IPCC) System

The in-pit crushing and conveying (IPCC) systems are attracting more and more attention from researchers and practitioners in the mining industry, due to its advantages and benefits in comparison to the conventional ST system. The IPCC system mainly consists of the crusher and conveyor located in an open pit. The crusher is used to grind large ore blocks, and then the ground ore blocks are delivered to the surface through the belt conveyor. With the deep-mining process of an open pit, the conveyor needs to be extended while the crusher needs to be relocated at a new mining phase. An overhead view of an IPCC system in an open pit is drawn in **Figure 2**.

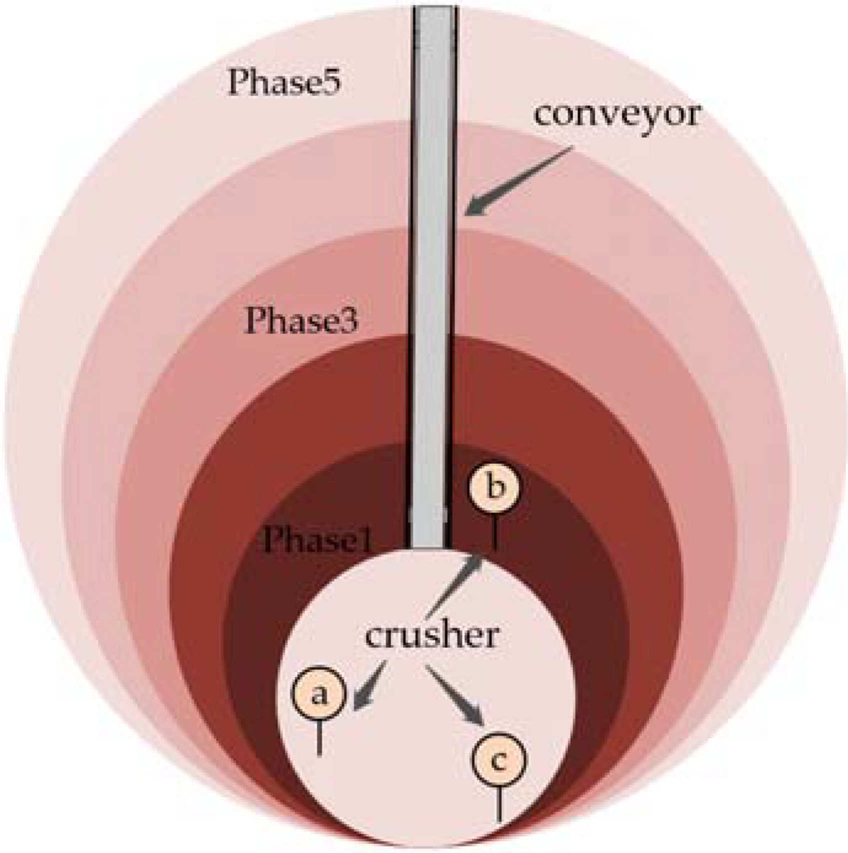

Figure 2. An overhead view of a sample IPCC system in an open pit in which there are one conveyor and three crushers (a–c).

As in **Table 1**, main characteristics of recent works on the IPCC system are summarized in **Table 2**. According to the analysis in **Table 2**, some observations are made as follows. First, the number of publications on the IPCC system are much less than that of papers on the ST system, because the IPCC system is more complex than the ST system by nature. Second, most studies considered crushers and conveyors simultaneously, while studies of a single equipment type (a crusher or a conveyor) are rare. Third, as the IPCC system is a continuous system, failure (e.g., a pause) of the IPCC system will bring substantial economic losses. Moreover, the extension of belt conveyors and the relocation of crushers have a significant impact on the production safety. Therefore, most of the problem types focused on the IPCC location and performance evaluation. In comparison, the IPCC production scheduling problem is relatively sporadic. Fourth, main solution approaches for IPCC management are based on mathematical programming. The development of more efficient solution approaches such as construction heuristics and hybrid metaheuristics for optimising the IPCC scheduling problem is a promising research direction.

Table 2. Characteristics analysis of publications on the in-pit crushing–conveying (IPCC) system [2][3][33][34][35][36][37][38][39][40][41][42][43][44].

Authors	Year	Country	Problem Types	Solution Techniques
Gu et al.	2021	China	Layout optimisation of IPCC	Particle swarm optimisation algorithms
Liu and Pourrahimian	2021	Canada	IPCC production scheduling	Mixed integer programming
Shamsi and Nehring	2021	Australia	Optimal transition point between IPCC and ST	Analysis of cumulative discounted costs
Wachira et al.	2021	Kenya	Performance analysis of SMIPCC	Mine productivity index
Paricheh and Osanloo	2020	Iran	IPCC planning with OPMPS	Mixed integer programming

Authors	Year	Country	Problem Types	Solution Techniques
Samavati et al.	2020	Australia	IPCC production planning and scheduling	Integer non-linear programming
Hay et al.	2020	Australia	Ultimate pit limit determination for SMIPCC	Block model and network flow algorithm
Yakovlev et al.	2020	Russia	Flow diagrams of IPCC	Cyclical-and-continuous method
Abbaspour et al.	2019	Germany	Optimum location and relocation of SMIPCC	Transportation problem and scenarios analysis
Paricheh et al.	2018	Iran	IPCC location and timing problem	A heuristic approach
Paricheh et al.	2017	Iran	IPCC location problem	Mixed integer programming
Yarmuch et al.	2017	Chile	IPCC location evaluation	Markov chains
Schools	2015	USA	Condition monitoring of IPCC	Condition monitoring technology analysis
Roumpos et al.	2014	Greece	Optimal location and distribution point of IPCC	Simulation modelling

4. Hybrid IPCC-ST System

Despite the rising trends in using the IPCC system, some mining companies are still hesitating to use IPCC in their mining operations due to reliability and flexibility concerns. To improve mining reliability and reduce unexpected risks, a more flexible framework is needed to make proper transition decisions between IPCC and ST systems to satisfy the location and relocation of the semi-mobile crusher.

Table 3 concludes the main characteristics of papers on the hybrid IPCC-ST system, which contains various mining equipment types such as trucks, shovels/excavators/loaders, conveyors, and crushers. As shown in **Table 3**, some insightful findings are presented. First, from the perspective of problem types, evaluation factors involved on the hybrid IPCC-ST system focused on the evaluation criteria with the consideration of environmental, social, economic, reliability and safety factors. Environmental factors include greenhouse gas, harmful gas, particular substance, and waste dumps. Efficiency factors mainly concern fuel consumption of each equipment and energy efficiency of the whole mining system. Social factors contain employment rates and salary levels. Economic factors are generally related to purchasing, renting, operating and maintenance costs. Safety issues refer to the reliability, failure rates of equipment and security of personnel. As the emphasis was placed on the performance evaluation, most papers tended to evaluate the economic value, production efficiency and environmental protection of the hybrid IPCC-ST system; but occasionally consider the system robustness, safety issues, economic factors and social indicators. Second, the majority of solution techniques for system performance evaluation are based on the multi-criteria decision-making methods. Third, due to its intrinsic complexity, the planning and scheduling optimisation methodology for the hybrid IPCC-ST system is scarce in the current literature.

Table 3. Characteristics analysis of publications on the hybrid IPCC-ST system [45][46][47][48][49][50][51][52][53][54][55][56][57][58][59][60][61][62][63][64][65][66][67][68][69][70].

Authors	Year	Country	Problem Types	Solution Techniques
Patyk and Bodziony	2022	Poland	Equipment selection in a surface mine	Multi-criteria decision-making methods
Chinnasamy et al.	2022	India	Introduction of ELECTRE for MCDM	fuzzy DS-ELECTRE
Shamsi et al.	2022	Canada	Production scheduling optimisation of hybrid IPCC-ST	Mixed integer programming
Krysa, Bodziony and Patyk	2021	Poland	Raw materials transportation	Discrete simulation
Kaźmierczak and Górniak-Zimr	2021	Poland	Accessibility of non-metallic mineral deposits	Evaluation and classification
Purhamadani et al.	2021	Iran	Energy consumption of IPCC-ST	Data analysis

Authors	Year	Country	Problem Types	Solution Techniques
Bernardi et al.	2020	Canada	Comparison of fixed and mobile IPCCs and ST	Discrete event simulation
Kawalec et al.	2020	Poland	Transition and replacement between IPCC and ST	Data analysis
Almeida et al.	2019	Brazil	ST system versus IPCC system	Environmental and economic comparison
Ghasvareh et al.	2019	Iran	Haulage system selection in open-pit mining	Multi-criteria decision-making methods
Nunes et al.	2019	Canada	Comparison analysis of SMIPCC and ST	Multi-criteria decision-making methods
Abbaspour et al.	2018	Germany	Selection analysis of ST and IPCC	Evaluation of safety and social indexes
Nehring et al.	2018	Australia	Strategic mine planning for ST and IPCC	Mine planning and evaluation
Özfirat et al.	2018	Türkiye	Selection of coal transportation mode	Fuzzy analytic hierarchy process
Rahimdel and Bagherpour	2018	Iran	Selection analysis of ST and IPCC	Multi-criteria decision-making methods
de Werk et al.	2018	Canada	Cost analysis of material handling systems	A Monte Carlo simulation
Braun et al.	2017	Germany	Sustainable technology diffusion of ST and IPCC	Data analysis
Patterson, Kozan and Hyland	2016	Australia	Integrated open-pit coal mining system	Mixed integer programming
Yakovlev et al.	2016	Russia	Conveyor-and-truck haulage system evaluation	A cyclical-and-continuous method
Liu et al.	2015	China	Energy consumption and carbon emissions of IPCC-ST	Power consumption calculation model
Rahmanpour et al.	2014	Iran	Comparison analysis of IPCC and ST	Analytic hierarchy process
Norgate and Haque	2013	Australia	Greenhouse gas impact of IPCC and ore-sorting	A life-cycle assessment method
Vujić et al.	2013	Serbia	Equipment Selection of Excavator–Conveyors–Spreader	Multi-criteria decision-making methods
Abedi et al.	2012	Iran	Analysis of mineral prospectivity mapping	ELECTRE III method
Bazzazi et al.	2011	Iran	Equipment selection of IPCC-ST	Fuzzy multiple-attribute decision making
Owusu-Mensah and Musingwini	2011	Ghana	Evaluation of ore transport options	Multi-criteria decision-making methods

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