Mining Calculator: Selection and dimensioning as well as economic and ecological analysis for bulk material handling systems in surface mining and civil engineering

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ABSTRACT

Sufficient and reliable supply of mineral commodities is an indispensable basis for the development and performance of any industrialized economy. In terms of statistical figures, every citizen of the Federal Republic of Germany consumes during an average 78 year life time more than 950 tons of mineral raw materials like fossil fuels, metallic ores, industrial minerals and aggregates.

Due to economical growth of developing countries and a rapidly growing world population the demand for mineral commodities increased year by year, accelerating in the last decade to new records. Actually more than 12 bn tons of solid mineral commodities are mined per year. In combination with unavoidable non-productive masses of overburden or burden ground estimated at around 28 bn tons a total mass of more than 40 bn tons is moved within mining operations.

As internal mass transport in the mine is estimated to cover about 25 % of total energy consumption of mining projects and thus is an important issue regarding costs and greenhouse gas emissions, haulage is an interesting field for optimization.

Basis for any optimization is predominantly a technical and economical evaluation of the employed or planned system and the final comparison of results for different possible solutions. Nevertheless beside technology and costs, environmental aspects come more and more into the focus of society, politics and authorities and thus of decision makers of the mining industry.

The Mining Calculator software offers the opportunity for the optimization of surface mining and earthmoving projects, based on a technical, economical and environmental evaluation, integrating various machine types and, uniquely, both discontinuous and continuous haulage systems. One project can be simulated with different loaders and haulage systems, leading to a user defined comparison of variants and finally provides a solid base for strategy and investment decisions.

INTRODUCTION

Mining has been a growing industry during the last decade despite some financial crisis affecting the world market conditions. The market growth of emerging or developing countries, especially China, led to a global boom in mineral commodity consumption joined by rapidly rising commodity prices. Based on these high prices mining companies spend

huge investments in exploration, in opening new mines or expanding existing mines as well as in equipment updates/upgrades for production increase in order to boost sales.

In recent times surface mining technology became more and more predominant for world mine production. Most important reason is that ore grades of known deposits have been constantly decreasing and underground mining is usually only feasible on high grade ores. As an example copper deposits have been considered feasible at minimum grades of 2 % in the past, while actually operating copper open pits have average grades less than 1 %.

But mining of low grade ores needs large equipment and high production capacities to be economical. Huge mining excavators and trucks as well as huge crushers, mills, etc are the base for modern mining operations. Examples for copper pits are the Escondida, Chuqicamata, Bingham Canyon or Grasberg, moving each hundreds of million tonnes per year.

Another trend in surface mining is that open pits are getting deeper, reaching up to a depth of even 1,000 m resulting in increasing haulage distances and cycle times of trucks as well as the necessary number of machines. Even if engine and truck efficiency has been optimized permanently, haulage costs are critical as they are sensitive to fluctuating fuel prices.

Partly or total reduction of fuel consumption is possible by substitution by electrical driven haulage. In recent time trolley-assist systems have had some renaissance. Most modern developments are large inpit crushing and conveying systems, so called IPCC allowing belt conveying at an early stage in the pit.

Beside this economical assessment ecological aspects are into the focus of mining companies. Surface mining in combination with processing and refining usually causes impact on surrounding neighborhood e.g. by dust, noise or toxic fumes pollution. As mining projects do attract rising public attention and legal and regulatory requirements have tightened up, minimizing these impacts are getting more important in order to raise acceptance and eligibility for granting a permit.

Anyway, every mining project needs custom-tailored concepts for an optimized loading and haulage system. This is valid for both Greenfield and Brownfield projects. At that point the software Mining Calculator offers technical, economical and ecological support for investment decisions for a specific mining concept or the assessment of the optimization potential of the actual employed system.

MINING CALCULATOR – KEY FEATURES AND TARGETS

The Mining Calculator software offers the opportunity for the optimization of surface mining and earthmoving projects, based on a technical, economical and environmental assessment, integrating various machine types and, uniquely, both discontinuous and continuous haulage systems. One project can be simulated with different loaders and haulage systems, leading to a user defined comparison of variants and finally provides a solid base for strategy and investment decisions.

The software includes equipment selection and dimensioning as well as cost calculation and determination of CO_2-emissions for discontinuous and continuous haulage. Thus, in a single step different scenarios can be compared and evaluated by illustrating the results in various diagrams and tables.

For material loading purpose hydraulic shovels, electric rope shovels and wheel loaders are available. Discontinuous haulage by mining trucks or articulated trucks as well as continuous belt conveying can be chosen. As the software works independently from

equipment manufacturers no brand or model names are displayed. Instead, machine classes are defined, orientated at the product portfolio of the actual market. The name of each type consists of the abbreviation of the machine type and relevant machine parameters, e.g. loader gross weight and standard shovel volume. For example the range of hydraulic excavators starts with a machine weight of 60 t with a regular shovel volume of 4 m³ up to a gross machine weight of 1,000 t with 50 m³ shovel capacity while mining trucks payload ranges from 40 t to 360 t.

Orientated at the range of frequent practical tasks within mine optimization for both Brown- or Greenfield projects the software allows a comparison of different scenarios, e.g.:

- Optimization of actual pit
    - Overall evaluation of equipment alternatives, e.g.
        - Different loader and truck sizes
        - Implementation of IPCC versus truck haulage
    - Cost analysis of improved haul roads

- Forecast of future mining phases as the open pit will get deeper or the mining face advanced horizontally with resulting impact on haulage distances
    - Calculation of the number of additional trucks
    - Truck size evaluation to increase cost efficiency
    - Comparison of haulage alternatives, e.g. different loader and truck sizes or implementation of IPCC
    - Determination of necessary crusher relocation periods

- Changes of production rate or operating hours
    - Fleet utilization and cost analysis
    - Cost analysis of possible changes within the machine setup

- Sensitivity analysis
    - Economical effects of fuel price fluctuation
    - Ecological evaluation of different power generation systems

The above listed practical applications do only give a brief overview over possible benefits, which can be achieved by software based analysis. Due to the flexibility of the Mining Calculator the user can work on highly individualized problems.

The following sections provide an insight into software operation. Screenshots of the software give impressions of project development and analysis. As the number of reasonable pictures as well as printable resolution is limited further information can be gathered on the Mining Calculator homepage.

DATA INPUT
Project basics
In a first step basic project data like material type and characteristics as well as annual production is requested.
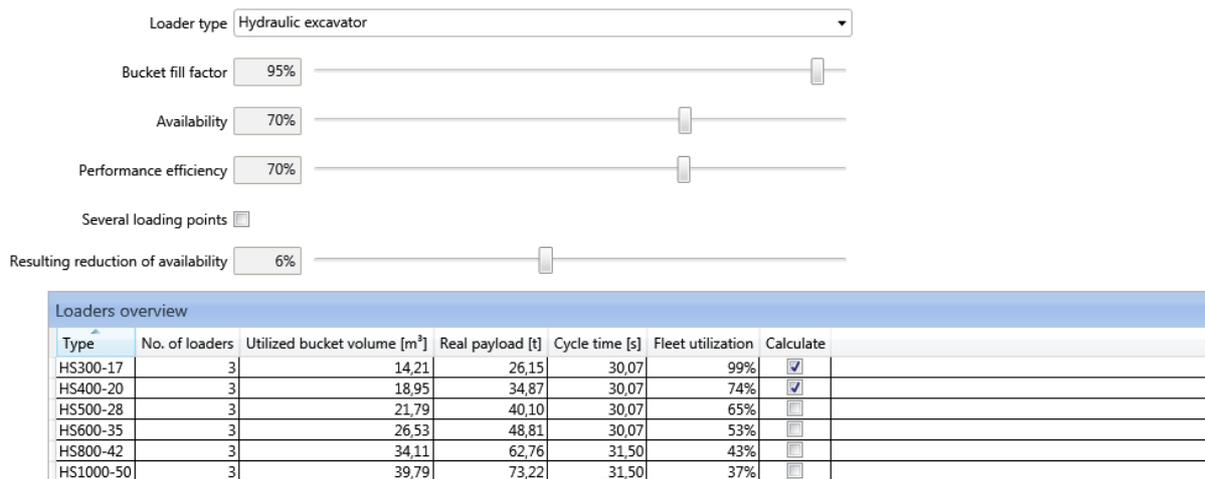
The program database offers a large variety of different mineral commodities with specific properties, e.g. solid and bulk densities as well as swell factors. Those default values can be adjusted individually to practice by the user to, depending on the project specifics.

Further important basic values for dimensioning of equipment are the total annual operation hours and the requested production. Usually the total production composes of simultaneous production at several loading points. Therefore the calculation methodology of the Mining Calculator is based on individual performance calculations for each loading point, which are combined to an overall project calculation result.

Loading

Once the basic project parameters have been defined, selection of the loading machine type directly leads to a list of possible machine types. By adjusting bucket fill factor, availability and performance efficiency, machine performance and utilization are fit to specific project conditions.

In principle at each loading point one loading machine is operating exclusively. The selection box "several loading points" offers the allowance for loaders to operate at multiple loading points in order to raise fleet utilization, taking into account that machine availability decreases due to reduction of available loading time by travelling times.

Type	No. of loaders	Utilized bucket volume [m³]	Real payload [t]	Cycle time [s]	Fleet utilization	Calculate
HS300-17	3	14,21	26,15	30,07	99%	☑
HS400-20	3	18,95	34,87	30,07	74%	☑
HS500-28	3	21,79	40,10	30,07	65%	☐
HS600-35	3	26,53	48,81	30,07	53%	☐
HS800-42	3	34,11	62,76	31,50	43%	☐
HS1000-50	3	39,79	73,22	31,50	37%	☐

Figure 1: Dimensioning and selection of loaders

Haulage

The Mining Calculator integrates discontinuous and continuous haulage systems, namely off-highway and articulated trucks, as well as belt conveyors.

The given number of loading points results in a corresponding number of haul roads, which have to be defined rather by entering different sections or upload of a predefined track in a text file. Haul road properties are defined by section length, grade and rolling resistance. The track profiles are interactively visualized for a better control of data input.

Definition of belt conveyors covers belt length and grade. A single belt conveyor, meaning one closed belt, can compose of several sections as well as a series of connected individual belt conveyors can be edited.

Equipment selection and Filtering

Based on input values, performance data of different systems and internal calculations, all adequate equipment combinations are computed and displayed in tables. To avoid

excessive data in further calculation steps and final visualization of results, the user may preselect and thus reduce the number of equipment combinations to be considered.

Discontinuous haulage

Count	Loading	Count	Truck type	Passes	Capacity utilization transport fleet	Real payload [t]	Payload utilization	Body volume utilization	Calculate
3	HS300-17	36	T55	2	88%	52,30	95%	81%	☐
3	HS300-17	36	T65	2	90%	52,30	80%	68%	☐
3	HS300-17	27	T90	3	88%	78,45	87%	71%	☐
3	HS300-17	27	T100	3	88%	78,45	78%	71%	☐
3	HS300-17	18	T140	5	88%	130,75	93%	97%	☐
3	HS300-17	16	T160	6	87%	156,90	98%	109%	☑
3	HS300-17	12	T220	8	89%	209,19	95%	88%	☐
3	HS400-20	28	T90	2	89%	69,73	77%	63%	☐
3	HS400-20	28	T100	2	89%	69,73	70%	63%	☐
3	HS400-20	16	T140	4	91%	139,46	100%	104%	☑
3	HS400-20	16	T160	4	89%	139,46	87%	97%	☐
3	HS400-20	11	T220	6	91%	209,19	95%	88%	☑
3	HS400-20	9	T300	8	90%	278,93	93%	89%	☐
3	HS400-20	9	T330	9	85%	313,79	95%	92%	☐

Necessary body volume exceeds standard body, caused by low bulk density

Figure 2: Output-table of equipment combinations

Furthermore an initial performance analysis for the selected equipment combinations is offered by charts and tables. Each preselected equipment combination can be displayed at all loading points showing e.g. speed profiles of trucks and haulage cycle times.
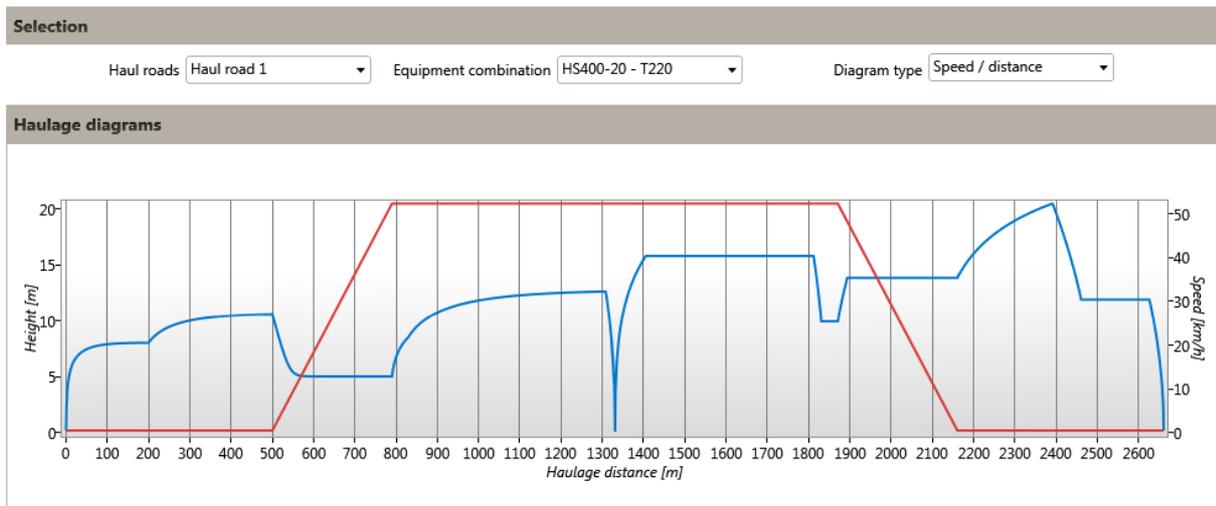
Figure 3: Haul road profile and truck speed

Costs and Environment

In a first step basic parameters for all machines are requested. This general data input is followed by machine-specific forms for all loaders, haulers and/or belt conveyors, necessary for cost calculation and determination of CO_2-emissions of the different systems.

The most important elementary data consists of the fuel price, the electricity tariff and power consumption as well as the CO_2-emissions, depending on different types of electric power generation.

Fuel consumption of diesel-driven, mobile equipment covers a wide range and is significantly influenced by the operational conditions of the project. Under extremely poor conditions, the diesel consumption of trucks can be nearly doubled in comparison with optimum conditions. Since the conditions are the same for all selected machines, a flat

default of the fuel consumption for both loaders and trucks can be set in three categories, min, med or max. Based on this predefinition, machine type specific consumption is calculated later on.

Since the power consumption for belt conveyor systems is explicitly based on the calculated drive power and operating hours, so at this point no input for continuous transport systems is required.

Diesel-powered equipment does not have alternatives for fuel, so that calculations of CO_2-emissions are based on a fixed value of 2.65 grams of CO_2 per liter of combusted diesel. CO_2 emissions of electrically-driven equipment are directly related to the type of power generation, which can be chosen from a list or entered as a project-specific value.

All individual machines within the selected equipment combinations are listed in individual folders. Machine-specific data must be edited as the base for the economical and ecological assessment of each equipment combination and the final comparison of results. The basic structure of the forms is the same for all machine types and is divided into the two categories of costs of capital and operating costs. Finally, an overview of capital, operating and total costs is displayed.

Capital cost [USD/oh]	
Purchase price [USD]	3.000.000
Residual value [USD]	0
Calculatory machine life [h]	19.000
Depriciation [USD/oh]	157,89
Interest expense [USD/oh]	28,35
Insurance costs [USD/oh]	4,05
Tax costs [USD/oh]	4,05

Operating costs [USD/oh]	
Salary [USD/oh]	50,00
Fuel consumption (full load) [l/oh]	198
Fuel consumption (real) [l/oh]	196,64
Fuel costs [USD/oh]	294,97
Crawler cost base factor [USD/oh]	21,20
Operational conditions multiplicator	0.9
Crawler track costs [USD/oh]	19,08
Consumable costs [USD/oh]	44,25
Maintenance costs [USD/oh]	50,11

Costs overview	
Σ capital costs [USD/oh]	186,10
Σ operating costs [USD/oh]	458,40
Overall costs [USD/oh]	644,50

Figure 4: Cost data input and calculation of specific costs

When implementing an alternative loading and haulage solution, additional costs can be generated, which are not covered by data input for equipment. Examples are costs for relocation of the primary crusher or extensive earthworks for new haul roads or conveyor tracks. To give consideration to this fact, the user can finally enter additional investments, which are integrated in the cost calculation as the sum of depreciation and interest.

Results and Data Evaluation

The final summary table includes all chosen equipment combinations and displays the most important calculation results, e.g. costs per ton, grams of CO_2 per ton or operation costs per hour. Right click at the column head offers additional result categories like total investment, number of operators etc. By sorting the table by any column, the user can easily analyze the table and focus on most important criteria.

Results

CO2 emision range [g/t]	891 - 1.011
Costs range [USD/t]	1,02 - 1,08

Summary

Count	Loading	Count	Truck type	Passes	Operating costs [USD/oh]	Capital cost [USD/oh]	Overall costs [USD/oh]	Overall costs [USD/t]	CO2 emission [g/t]
3	HS300-17	16	T160	6	5.268,93	1.743,57	7.012,49	1,08	891
3	HS400-20	16	T140	4	5.030,53	1.820,41	6.850,94	1,05	958
3	HS300-17	12	T220	8	5.089,48	1.643,78	6.733,26	1,03	972
3	HS400-20	11	T220	6	5.000,32	1.679,86	6.680,19	1,02	1.011

Figure 5: Calculation results table

In addition to the resulting data table, a variety of diagrams is available for graphical analysis of the resulting data. Different dual bar charts, based on two individually selectable calculation parameters, can be created. Furthermore an individual analysis of the cost structure for a selected project variant can be performed by pie charts, showing either only the percentage ratio between the capital and operating costs or a detailed partition with subcategories for both types of costs. Finally a direct comparison of the cost structure of two project variants is possible by choosing a second equipment combination, showing the percentage difference in specific costs.

All resulting data tables and diagrams can be exported either to spreadsheet analysis (e.g. Microsoft Excel) or via screenshot for integration in presentations or for documentation.

Project Comparison

Superior goal of the Mining Calculator is the comparison of different loading and haulage alternatives for a given project. This implicates, that ideally, all the basic project parameters, i.e. material properties and production rate, are identical for the chosen project alternatives. Therefore the software offers a copy function for the entire basic project, which can then be modified into a new project alternative, e.g. by changing the haulage system.

Finally the calculation results of all project alternatives in the workspace can be compared with each other to detect the overall optimum variant. The project comparison always includes two project alternatives. Similar to the evaluation of variants within a single project, the comparison of equipment combinations out of different project alternative is given out in a table and can be displayed in dual bar charts for all selectable calculation parameters and cost structure pie charts.
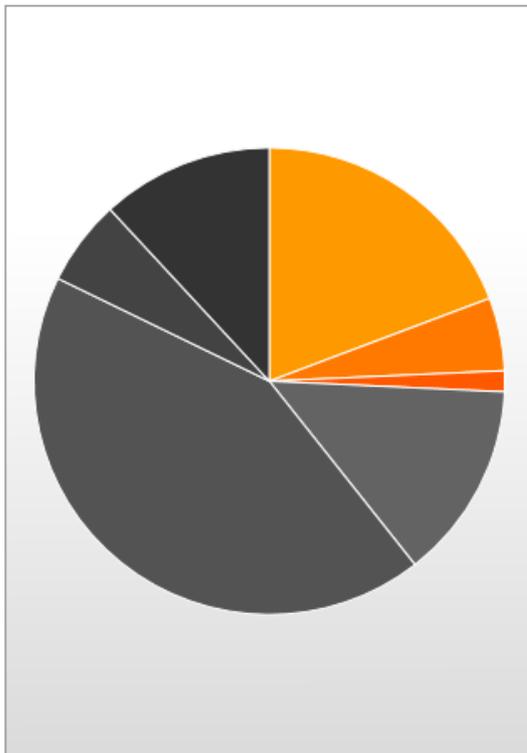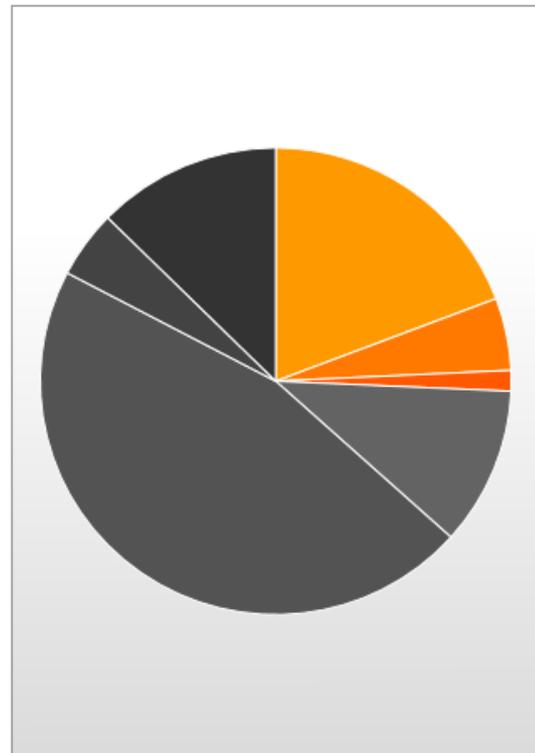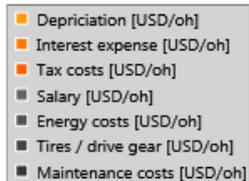
Figure 6: Comparison results - pie diagram

CONCLUSION

The Mining Calculator is a software for optimization of mass transport in mining and earthmoving projects. Frequent applications are the analysis of employed machine size classes at different mining phases, assessment of the establishment of an IPCC-system or the optimization of infrastructure by relocation of haul roads or grade reduction.

The software includes equipment selection and dimensioning as well as cost calculation and determination of CO_2-emissions for discontinuous and continuous haulage. Thus, in a single step different scenarios can be compared and evaluated by illustrating the results in various diagrams and tables.

Calculation results offer a reliable base for in-house decisions on technical aspects like equipment modifications, on economical aspects like specific cost per ton or total investments and finally on ecological aspects based on greenhouse gas emissions.

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