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Long-term economic sensitivity analysis of light duty underground mining vehicles by power source

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ABSTRACT

LHD's are expensive vehicles; therefore, it is important to accurately define the financial consequences associated with the investment of purchasing the mining equipment. This study concentrates on long-term incremental and sensitivity analysis to determine whether it is feasible to incorporate current battery technology into these machines. When revenue was taken into account, decreasing the amount of haulage in battery operated equipment by 5% or 200 kg per h amounts to a $\$4.0 \times 10^4$ loss of profit per year. On average it was found that using battery operated equipment generated $\$9.5 \times 10^4$ more in income annually, reducing the payback period from seven to two years to pay back the additional $\$1.0 \times 10^5$ investment of buying battery powered equipment over cheaper diesel equipment. Due to the estimated 5% increase in capital, it was observed that electric vehicles must possess a lifetime that is a minimum of one year longer than that of diesel equipment.

1. Introduction

Mining equipment is expensive, not only to acquire but also to maintain. Depending on the terrain where the mining operation is located it may be difficult to obtain resources necessary to maintain the equipment. Mining is also a very energy intensive process requiring both electricity and fuel to provide energy equipment operation [1,2]. The majority of load haul dump vehicles, LHDs, in underground mining operations are currently powered by diesel. However, with recent advancements in battery technology it is becoming more feasible, both physically and economically, to convert larger equipment, such as LHDs, from diesel power to battery [3–5]. Lithium ion and sodium metal halide, NaMx, batteries are an optimal choice for use in the harsh underground mining environment LHDs operate in. These technologies are compact, durable, relatively inexpensive, and easy to manufacture to scale [6,7]. These benefits make LHDs powered by these technologies a great improvement over the currently used lead acid technology. In a previous study, the performance analysis for diesel and tethered electric LHD fleets was calculated using data acquired from a Peruvian underground mine. It was observed that the electric vehicles not only required less planned maintenance but also broke down less often leading to lower unplanned maintenance as well [8].

In addition to performance analysis, a detailed, long-term, economic analysis of both electric and diesel powered mining vehicles was performed to properly gauge which equipment power source brings the most benefit to underground mines. In this study, LHD's were examined with respect to their power sources. Battery powered and electric and diesel powered LHD's were studied and the data related to their power types were used to generate an economic model. Data from the same Peruvian Mine used in the previous study was also used in the economic model. The model, generated, in house calculated the present value, in both nominal and constant dollar values, net present value, internal rate of return cumulative value and payback period. The data calculated for the two equipment power sources were compared using incremental analysis. The comparison was then tested using sensitivity analysis to determine a range of profitability for each vehicle power source.

2. Methodology

2.1. Economic indicators

The economic analysis was performed, considering several variables, to accurately define the investment required for purchasing

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the mining equipment. The following economic analyses were determined in this project and the results compared between battery powered and electric and diesel powered equipment. The main economic indicators, explained in further detail below, include present value (PV), net present value (NPV), internal rate of return (IRR), constant dollars (CD), cumulative value (CV), and payback period. The two methods of analyzing the aforementioned indicators are incremental analysis and sensitivity analysis, also expanded upon below [9,10].

2.1.1. Present value, net present value, and internal rate of return

Present value, also known as present discounted value, is a future amount of money that has been discounted to demonstrate its potential buying power if it existed today. Due to the interest earning potential of money, also referred to as the time value of money, the further from the present the money is acquired, the lower the present value will be. Present value is used to calculate net present value, which is the sum of the present values over the lifetime of the project. In this study, NPV is used to define the net profit over each vehicle's lifetime in current value. The internal rate of return is used to compare the profitability of investments, but IRR does not take interest and inflation into account, therefore focusing on a projects profitability. IRR is used in conjunction with NPV to help determine the value a particular investment. It expands upon the information the NPV provides, whether the investment is a net income or loss, by providing a percentage of increase over the lifetime of the project. A company can set a bare minimum percent return on investment, known as a hurdle rate, to ensure payback periods within acceptable limits.

2.1.2. Constant dollars

The purchasing power of the dollar changes over time due to inflation, so in order to compare dollar values from one year to another, they need to be converted from nominal (current) dollar values to constant dollar values. Also identified as the real dollar value, constant dollars allow the visualization of consistent revenue and expenditures at set inflation rates over the lifetime of the project.

2.1.3. Cumulative value and payback period

Cumulative value is when the present value is added cumulatively over time, with the value at project termination being the net present value. Cumulative value is used in this project to determine the payback period by noting the length of time the CV is negative. Payback period is the length of time required to acquire the initial investment from profits gained from the investment. The time value of money is not taken into account for payback period, however, it is a common method of determining how long something takes to "pay for itself". Equipment is generally selected with payback periods usually limited to a set percentage of the lifetime of the equipment to allow time for the equipment to generate its return on investment [11].

2.1.4. Incremental analysis

Incremental analysis is performed by comparing the differences in operating costs and profits between two tasks. In underground mining, incremental analysis can be used to compare two different equipment models considered for purchase. Comparing costs of the electricity to each machine, maintenance costs, efficiency, and also the productivity of the new mining vehicles can be aid in providing a complete picture of where each vehicle exceeds the other financially. The versatility of this analysis allows the determination of differences in operating expenses or overall costs.

2.1.5. Sensitivity analysis

Sensitivity analysis is used to give more detail on how rapidly changing variables, such as commodities, can affect the profitability of the equipment under review. The technique particularly is useful when a model contains a large number of input parameters, allowing for the observation of a range of profitability for each variable [12]. Only one variable, in the financial model, is changed at a time, all other variables remain constant, removing any constructive or destructive interference from other variables. NPV and IRR were both analyzed for the magnitude of effect of input adjustment and compared with that of the other vehicle power sources.

3. Results

3.1. Assumptions and variables

In this study, certain assumptions were made while developing the economic model used to assess the value battery vehicles that bring to the mine. First, due to the fact that LHDs, haulers, and drilling jumbos are similarly constructed, it was assumed that the economic model created in this study would be useful in estimating value of a vehicle of similar construction to light duty LHDs. The battery equipment was assumed to have similar maintenance to tethered equipment and similar logistical downtime to diesel vehicles. The economic model was conducted over a 35 year period to account for several equipment life cycles so that a fair account could be taken of each vehicle type. The length was decided to establish a period of the least common multiple of battery/battery pack and diesel lifetimes. The capital costs for the equipment and battery packs were assumed to remain constant over the length of the study. Though on the long side, the length is short enough to be considered the life of a typical mine. The assumed lifetimes for the equipment were 7 years for diesel and 10 years for electric, based on the average lifetimes of electric and diesel equipment in the Peruvian mine data used in this study. The economic model required several variables that could be categorized in one of two major categories, equipment dependent and equipment independent variables.

3.1.1. Equipment dependent variables

Equipment dependent variables, shown in Table 1 below, include capital cost, maintenance, annual tonnage, operating hours, energy consumption and energy cost. The battery cost was estimated by rounding up \$128,964 to $\$1.3 \times 10^5$ based on cost, calculated in a previous study, for a 4 h battery [13]. Operating hours were calculated using the data set. Diesel averaged 219 h of uptime per month giving an estimated annual total of 2628 h per year. Since batteries were estimated to have 5.5% more uptime the monthly average increased to 231 h, giving an annual total of 2772 h per year. Tonnage was also obtained by taking the average monthly data for diesel equipment and estimated for batteries by increasing it by 5.5%. Maintenance costs were taken from the data set for tethered and diesel equipment as well. The same value for tethered equipment was used for battery equipment. Energy

Table 1
Equipment dependent control values.

Item	Diesel	Tethered electric	Battery
Vehicle price (\$)	2000000.00	1950000.00	2100000.00
Maintenance cost (\$)	78000.00	55000.00	55000.00
Tons moved	34,620	25,164	36,524
Battery replacement (\$)			130000.00
Operating hour (h)	2628	2628	2772
Consumption (kW Or L/h)	11	64	100
Total energy cost (\$)	33901.20	23546.88	38808.00