Energy efficiency metrics in mine design

Michael Britton

Prof. Melinda Hodkiewicz
School of Mechanical and Chemical Engineering

Adrian Kefford (Client Mentor)
Steve McDonald, Graeme Chivers and Greg Lawson
CEED Client: Leighton Contractors Pty Ltd

Abstract

The recent implementation of the carbon tax and reductions in diesel rebates, as well as rising fuel prices, have seen the Australian mining industry shift its focus towards improving the management of energy efficiency. Leighton Contractors Pty Ltd ("Leighton") has identified an opportunity to improve the identification of energy saving initiatives in haulage operations during mine design. Conceptually, it is understood that improved opportunity identification can be achieved through the utilisation of previously developed energy efficiency metrics, titled the Le3 equations. The aim of this project is to ascertain the effectiveness of the Le3 equations in improving energy efficiency and provide a tool to assist Leighton in delivering demonstrated energy efficient mine design concepts to its clients.

The project develops an energy benchmark to assist in the analysis of the energy efficiency of haulage operations during mine design. In addition, a case study at the Telfer gold mine is conducted to review the applicability and commercial appropriateness of the utilisation of energy efficiency metrics. The results indicate that energy efficiency metrics are an effective tool for prioritising potential opportunities to reduce the energy intensity of haulage processes.

1. Introduction

As a result of the Energy Efficiency Opportunities ("EEO") program introduced by the Federal Government in 2006, which requires businesses to identify, evaluate and report annually on cost effective energy savings opportunities, Leighton Contractors Pty Ltd ("Leighton") identified the need to better measure energy efficiency (Australian Government Department of Resources, Energy and Tourism 2012). Subsequently, the Le3 method was developed as a result of research and development work undertaken by E3k Consulting ("e3k") in conjunction with Leighton. The Le3 method, in theory, provides a means for Leighton to compare the energy efficiency of its haulage fleet at any point in time with an established energy efficiency benchmark.

In addition to the work performed by e3k, industry and academic research has been conducted in the broad areas of mining and vehicle energy efficiency. Fortescue Metals Group examined the energy cost savings associated with minimising the unnecessary stopping of haul trucks, optimising haul truck engine controls and reducing idle times in rail operations. The Downer Group, in an approach similar Leighton, developed operational haulage performance indicators that use an 'equivalent flat haul' calculation to account for elevation changes on a mine route (Department of Resources, Energy and Tourism 2010).

In a notable academic paper, Kecojevic and Komljenovic examined the fuel consumption and CO_2 emissions of haul trucks under various load factors. This study was however limited by access to data, and recommends in conclusion that future studies may focus on specific factors such as "acceleration, idle time, road grade maintenance and quality of road surface, and the operator's driving style" (Kecojevic & Komljenovic 2010).

A review of the existing research, including that performed by e3k, indicates a focus on the identification of opportunities to improve energy efficiency during operational stages of mining. The intention of this project will be to expand on the current understanding of energy efficiency management during the earlier mine design stage. Specifically, this project will build on previous work in this field in three ways. First, the project will expand on the work conducted by e3k to review the capacity of energy metrics to assist in the identification of opportunities to improve energy efficiency during a mine design stage. Second, with reference to recommendations discussed by Kecojevic and Komljenovic, the project will utilise existing data to investigate the relationship and effect that mine design has on energy efficiency. Third, in the context of the current macroeconomic and regulatory environments, the project will review the commercial appropriateness of the implementation of energy efficiency metrics during mine design.

2. Approach

The approach taken in this project required the development, design and review of energy efficiency metrics during mine design and consisted of a four step process. First, a review of existing energy efficiency metrics indicated that a method for identifying the energy intensity of a particular mine was required. A modification of the existing Le3 equations provided the capability to compare the theoretical energy intensity of a mining truck, for a given haulage route, to a minimum theoretical energy benchmark. This approach delivered what was titled the Mine Design Ratio ("MDR").

$$\mathrm{MDR} = \frac{\mathrm{E_2}}{\mathrm{E_1}} = \frac{\text{Theoretical energy consumed by Mining Truck}}{\text{Benchmark theoretical energy}}$$

In addition, to support the identification of key opportunities to reduce haulage distances and to assess the capacity of the MDR to identify energy intensive haulage routes, a more simplistic metric was developed, titled the Route Directness Measure ("RDM").

$$\mathrm{RDM} = \frac{\text{Haulage distance}}{\text{Direct distance from load to dump}}$$

Second, utilising the new and existing equations, a dynamic MDR model was developed in Microsoft Excel to readily draw from available mine data. This required the establishment of three dimensional haulage route coordinate information, in addition to assumptions around haulage fleet characteristics, rolling resistance and other mechanical friction factors.

Third, to assist in the review of the developed MDR model and to quantitatively identify the key drivers of energy efficiency, a sensitivity analysis was conducted. The sensitivity analysis utilised the Data Table functionality of Microsoft Excel to identify the change in energy efficiency for a given haulage route based on a $\pm 10\%$ change in key variables.

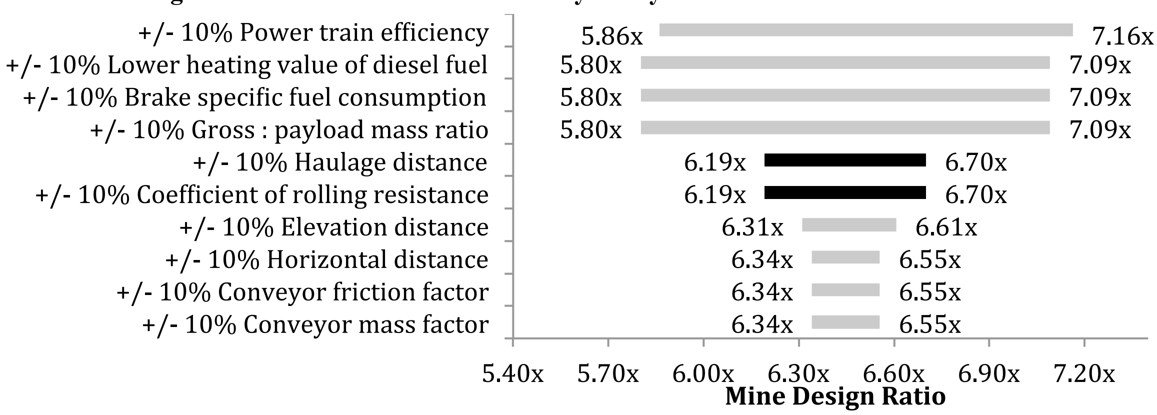
Finally, to investigate the appropriateness and applicability of the MDR model a case study was conducted for the Telfer Gold Mine ("Telfer") in Western Australia. The case study examined the energy intensity of the current design through the calculation of the MDR and RDM for all haulage routes from various depths of the pit as defined by their reduced level ("RL"). The consequent cost implications associated with improving the energy efficiency of the most energy intensive haulage routes is then examined through the development of a prioritised cost-benefit analysis. Accordingly, this process provided an assessment of the commercial feasibility of both metrics.

3. Results and Discussion

3.1 Sensitivity Analysis

The results of the sensitivity analysis conducted for Telfer indicated that the energy intensity of a given haulage route is most sensitive to factors associated with the mechanical efficiency and physical characteristics of the selected haulage vehicles. As discussed by e3k in their development of the Le3 equations, the mechanical efficiency of haulage can potentially be improved through the implementation of a conveyor system (Engineering3000 2007). The sensitivity analysis also confirmed that two of the key drivers of energy efficiency are haulage distance and rolling resistance (shown in black in Figure 1), both of which can potentially be reduced during mine design.

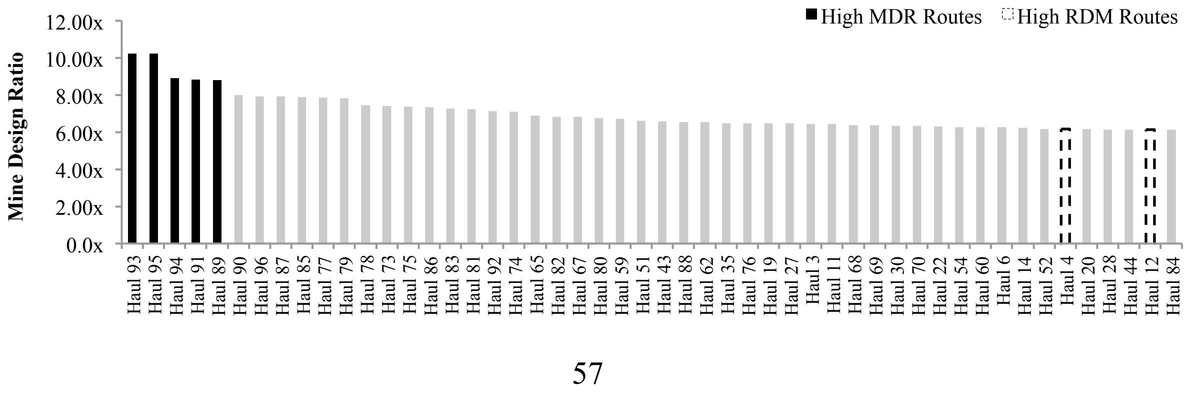
Figure 1 - Telfer Gold Mine Sensitivity Analysis



3.2 Mine Design Ratio

As seen in Figure 2, the calculation of the MDR for all haulage routes at Telfer showed a range of multiples. Conceptually, the value of the MDR can be interpreted as a multiple of inefficiency in comparing a mining truck to a minimum energy benchmark for a given haulage route. This implies that for the Telfer case study, the most energy inefficient haulage route consumes 10.24 times as much energy as the minimum energy benchmark to move a given mass of material.

Figure 2 - Telfer Gold Mine Design Ratios



The most energy intensive haulage routes identified were from shallow depths in the pit (5492RL) to the Mineralised Waste ("MINW") and Potentially Acid Forming ("PAF") stockpiles. Given the close proximity of both stockpiles (located within 430m of each other) an opportunity to improve energy efficiency existed through the implementation of an ex-pit overland conveyor supported by a primary crushing unit.

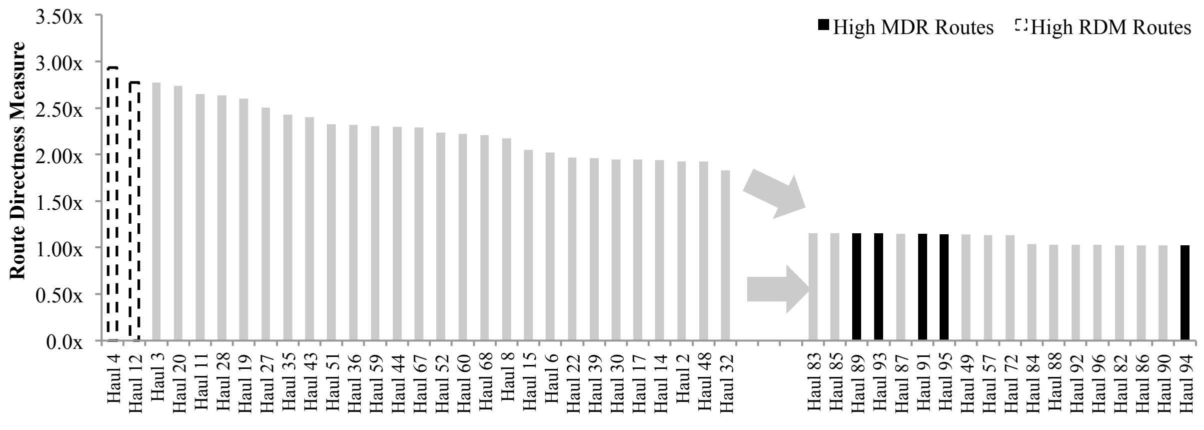
Based on cost related assumptions, the results of the financial review indicated that the cost of implementing an ex-pit conveyor was 9-10 times more expensive than truck haulage for the 307,993 banked cubic metres ("BCM") of material over 2,600m. The key driver of this additional cost was the capital expenditure required to construct the conveyor. However, it is evident that due to the generally lower operating costs of conveyors, the implementation of a conveyor becomes increasingly more economic as the volume of material increases along with the life of mine ("LOM") haulage distance.

With reference to this relationship between operating and capital costs for a conveyor, the MDR is unable to capture costs associated with mining processes and consequently additional cost-benefit analysis need to be undertaken to justify changes in mine design. However, as the haulage routes identified at Telfer were those over the most significant distances with negative changes in elevation, it’s evident that although the MDR may not be capable of conclusively identifying cost effective opportunities for the implementation of a conveyor, it is however able to prioritise the most cost effective opportunities for a given mine site.

3.3 Route Directness Measure

The calculation of the RDM for all haulage routes at Telfer provided some unique results. The RDM can be interpreted as a multiple of the additional distance required to travel between the load and dump due to both physical and self imposed boundary restrictions. The RDM provides an indication of the least direct haulage routes for a given mine, and consequently a prioritisation of opportunities to reduce haulage distance and improve energy efficiency.

Figure 3 - Telfer Gold Mine Route Directness Measures

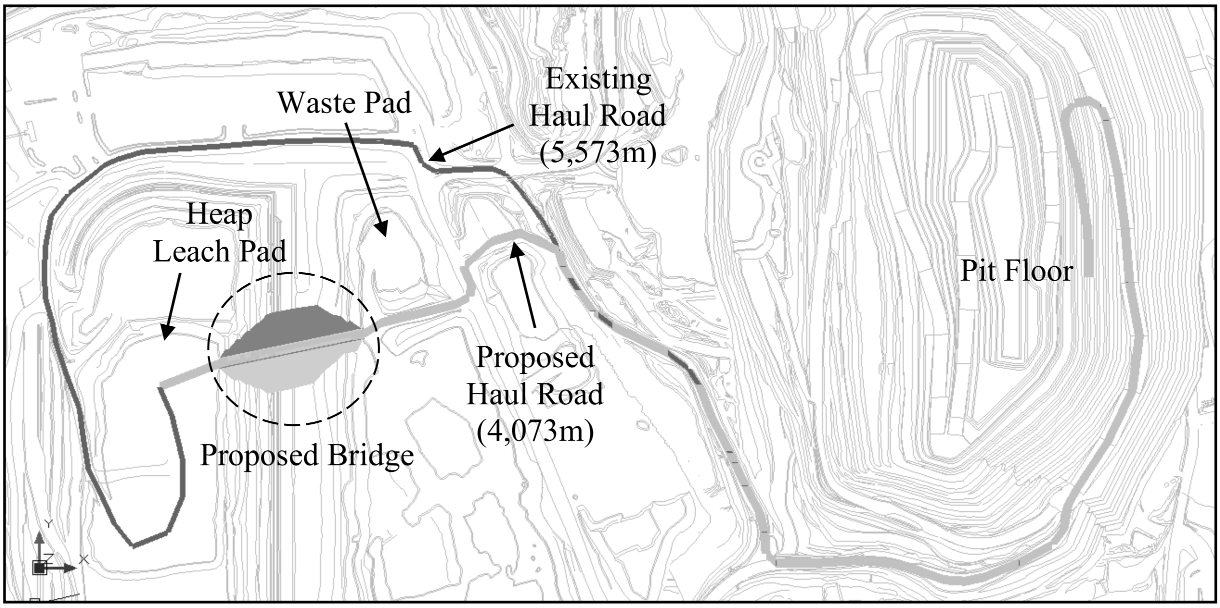


The least direct haulage routes identified by the RDM for Telfer were haulage routes from various bench heights in the pit to the Heap Leach pad, along a 5,573m haul road as shown in Figure 4. With a focus on this haulage route, the commercial feasibility of the RDM was examined through the identification of opportunities to reduce the haulage distance to the Heap Leach pad.

The test for commercial feasibility was based on the cost associated with the construction of a 330m bridge composed of 1,000 BCM of Outer Silstone Member ("OSM") material between the Heap Leach pad and a Waste pad as shown in Figure 4. This resulted in a reduction of the

Heap Leach route distance by 1,500m and an additional reduction of 980m for the haulage of the 5480RL OSM bench material. Consequently the cycle times for both haulage routes were reduced providing a reduction in the number of vehicles required to maintain effective utilisation of the three excavators in the pit, generating a potential cost saving. Based on these findings it is evident that the RDM has the capacity to focus the efforts of mining engineers towards prioritised opportunities to reduce haulage distances.

Figure 4 - Telfer Proposed Haulage Route

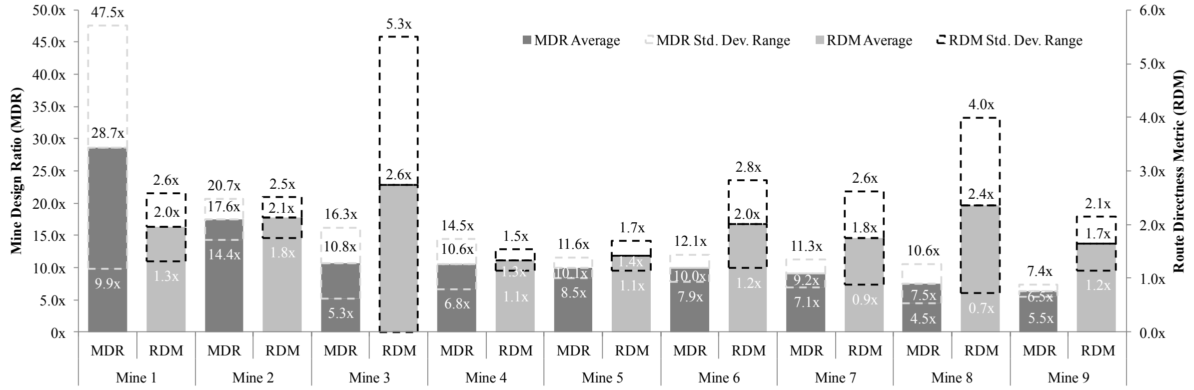


3.4 Review

The results of the calculation of the RDM for Telfer were interesting in that they did not necessarily coincide with the haulage routes identified as high priority opportunities to improve energy efficiency by the MDR, and was more capable of identifying opportunities to reduce haulage distance. A review of the structure of the MDR equations indicates (as shown in the sensitivity analysis) that haulage distance is only one of many contributing factors to the energy intensity of a haulage operation and its significance in the derivation of energy efficiency is dissipated relative to other variables. The issue with the implementation of the MDR is consequently its inability to prioritise the degree to which each energy factor can be managed during mine design as it combines all inputs into a cumulative energy intensity measure.

This is further emphasised in Figure 5, which shows the average MDR and RDM for various Leighton mine sites as well as the standard deviation of each metric, providing a measure of the range of values for all haul routes. The mine sites are ordered along the x-axis such that the MDR values are descending from left to right, and it can be seen that the average RDM values do not correspondingly decrease. Consequently, the diagram indicates that a decline in MDR is not necessarily correlated with a decline in RDM. More generally this concept implies that to effectively identify opportunities to improve energy efficiency, methods to measure the energy consumed by individual contributors to energy intensity need to be developed.

Figure 5 – Leighton Average Mine Design Ratio Site Comparison



4. Conclusions and Future Work

The Mine Design ratio and Route Directness measure, when used in parallel, provide effective tools to assist in the prioritisation of opportunities to reduce energy consumption. The MDR is capable of providing a high level insight into the energy intensity of operations, but individual factors need to be measured and isolated to more effectively identify opportunities for improved energy efficiency. In general, although energy efficiency metrics don't incorporate the cost of reducing energy intensity in their design, they have the capacity to act as a system in directing efforts towards prioritised opportunities to reduce energy intensity. This process becomes considerably more valuable in environments where time and resource constraints impede on opportunity identification as complex mine data can be analysed through the MDR and RDM models with relatively minimal effort. Furthermore, to support the economic justification of energy reduction initiatives, future work should focus on quantifying potential energy savings from changing energy drivers such as rolling resistance, acceleration, haulage distances, and driver patterns. In addition, examining the opportunity to further automate the implementation of energy efficiency metrics in engineering software or reviewing opportunities to improve the mechanical efficiency of haulage vehicles through the implementation of autonomous or electric vehicles, have the potential to add value to the field of energy efficiency management.

5. Acknowledgements

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