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The need for sustainable technology diffusion in mining: Achieving the use of belt conveyor systems in the German hard-rock quarrying industry

Tobias Braun*, Alexander Hennig, Bernd G. Lottermoser

Institute of Mineral Resources Engineering, RWTH Aachen University, Wuellnerstrasse 2, 52062 Aachen, Germany

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ABSTRACT

The movement of raw materials can be one of the most challenging tasks in open pit mining, with truck transportation representing the largest factor in mining costs and resulting in major greenhouse gas (GHG) emissions. In this study, the transportation methods of bulk materials within German hard-rock open pit mines were investigated. Approximately 450 quarries were studied for their production tonnage, lease areas, mined rock type as well as mining methods and processing equipment. The results demonstrate that 90% of the operations use truck-based transportation methods, with the remainder relying partly or completely on continuous conveyor-based systems. The installation of continuous conveyors compared to trucks represents a real alternative because of reduced dead load, reduced GHG emissions and in many cases even reduced costs. Thus, for in-pit haulage in quarries sustainable technology substitutions exist that are yet to be adopted by the German quarrying industry. As this study shows, in the future the diffusion of sustainable technologies requires site champions and large-scale case studies that demonstrate their successful introduction in the mining value chain.

1. Introduction

The pit and quarry industry is a significant economic enterprise in Germany, as this activity generates a yearly revenue of more than 3600 Million € and supports about 60 000 employees (Basten, 2011, 2015; DESTATIS, 2015a; StMWI, 2014). Every year, 550 Mt of materials are produced, making Germany self-sufficient in the production of crushed stone, sand and gravel (Babies et al., 2011; Schwarzkopp, Drescher, Goring, & Blazejczak, 2013). The largest products include: sands and gravel for construction works (238 Mt annual production), broken natural stones (211 Mt annual production) and carbonate rocks (64 Mt annual production) (Huy et al., 2015). Broken natural stones and most of the carbonate rocks are extracted in more than 1000 quarries in Germany, which are the subject of this study. With an energy consumption of 12.3% of the gross production value, the extraction of natural stones is one of the most energy-intensive industries in Germany (DESTATIS, 2015a). Overall, an annual energy consumption of 1900 Million kWh (DESTATIS, 2015a, 2016; DIHK, 2016; Huy et al., 2014; KTBL, 2012) is incurred, with emissions of about 0.57–1.15 Mt CO2-equivalents (Fritsche & Schmidt, 2007; Icha & Kuhs, 2015), depending on which energy source is used (DESTATIS, 2014, 2016; Frischknecht, Stucki, Flury, Itten, & Tuchschmid, 2012; Icha & Kuhs, 2015). As with other industrial minerals, only the extraction and processing of large masses of broken natural stones and carbonate rocks are economic. Extraction of these mineral resources is almost limited to open pits, and haulage distances up to several hundred meters from the loading point to the dumping area are common. Therefore, internal haulage greatly impacts on extraction costs (about 40%–50%) and energy consumption (about 40%) (Schmieder, 2007; Skrypzak, 2015; Vergne, 2014; Zimmermann & Kruse, 2006, pp. 481–487).

As a contribution to global climate protection, the European Union aims for a reduction of 40% of greenhouse gas-emissions (GHG) of all member countries by the year 2030 compared to the emissions of 1990. The German Government supports these targets with an even more ambitious program, which aims for a reduction of 40% by 2020 and eventually, even an 80%–95% reduction by 2050. Additionally, an increase in energy efficiency by 30% by 2030 should be achieved (Weiβ, Welke, Kahlenborn, & Brünig, 2015). Optimizing existing technologies and operational structures, or

* Corresponding author.
E-mail address: Braun@mre.rwth-aachen.de (T. Braun).

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substituting them with more energy-efficient and low-emission technologies can make a major contribution to this goal and to the sustainable development of the mining industry (Brewer, 2012; Dubiński, 2013).

The introduction of new and alternative technologies is often hindered by risk-barriers and inhibition. In addition to economic risks, reliable information can be missing for new technologies and their possible applications (Corazza, Guida, Musso, & Tozzi, 2016). The primary approach to handling these risk barriers and to reducing these inhibition thresholds, is to generate a broader knowledge base and to make information for branch-specific application potentials available. This can be realized through completed case studies with large sample sizes (Trianni, Cagno, & Worrell, 2013).

The present study is focused on the possible introduction of energy-efficient and low-emission technologies in German hard-rock quarries, while considering their economic impact and viability. Taking into account the economic and energetic importance of internal haulage, transportation of hard-rock commodities is the most significant bottleneck for optimization and, hence, changes in haulage systems are associated with significant uncertainties for the operation. Consequently, conventional transportation using dump trucks has rarely been substituted by other technologies. Yet, continuously working conveyor belts represent a promising alternative for transporting mined materials. Such technology has successfully been implemented in other areas of the raw material extraction business (Moore, 2011, 2012; Stoll, Niemann-Delius, Drebenstedt, & Müllensiefen, 2008). Here, the amount of dead load can be reduced by up to 80%, and local emissions can be prevented and generally down-sized (Norgate & Haque, 2013; Zimmermann & Kruse, 2006). The commonly recognized economic and technical application constraints, which limit the use of conveyor belts to implementation in open pits with great transportation distances, high production tonnages and primarily loose rock, are based on data and experiences from early applications of this technology (Goergen et al., 1987; Korak, 1978) and are therefore partially obsolete. Technological improvements in general and especially the technical advancement of mobile crusher units have loosened the application constraints for conveyor belts at least from a technical point of view (Darling, 2011; Turnbull & Cooper, 2009, pp. 60–77).

The majority of small quarry operations (Basten, 2011) commit to high entrepreneurial risk when testing a new technology in practice. Considering first of all that transportation in quarrying represents the biggest cost factor and secondly that currently neither a benchmark nor a characteristic reference operation for the implementation of alternative transport technologies exists, the implementation is perceived as high risk (Vergne, 2014). This in turn leads to the persistent use of approved conventional transport technologies. As a result, economic and, especially, sustainable optimization potentials through technology-substitutions are generally being ignored (Braun & Hennig, 2016).

The aim of this study is to quantify the sustainable and economic optimization potentials by applying belt conveyors in German hard-rock quarries. The results of this research contribute to continuously growing efforts to have more energy efficient and low-emission technologies applied in the extraction of mineral resources.

2. Methods

A comprehensive analysis of the German quarry industry was completed based on detailed analyses of public databases and published literature, extensive aerial photography examinations of individual mine sites and structured industry surveys. Initially, detailed aerial examinations were conducted on ~450 hard-rock quarries to capture geometric dimensions and optical ascertainable properties of individual mine sites. Subsequently, a structured and tailored research survey comprising a series of questions was submitted to selected pit and quarry companies. The survey questions covered operational and geological data, including production tonnage, lease areas, mined rock type, mining methods and processing equipment. The company survey was distributed to 120 quarry operations in Germany, with an overall response rate of 51% (for a detailed presentation of the survey see Braun & Hennig, 2016).

Additional data was gathered using publically available information. Since publically available data is limited and comprehensive documentation of German quarries is missing, the study had to rely on data gathered for a limited number of mining operations. Yet to ensure that the dataset accurately reflects the entire German hard-rock industry, a large quantity of quarries were chosen (n ~450) whose characteristics represent an unbiased indication of what the industry is like.

Moreover, historical data on energy consumption and equipment application in the German quarry industry (1990–2013) was evaluated. For this, a study on position optimization for primary crushers dating from the year 1990 and evaluating 56 quarries was examined (Stoll, Dohmen, & Platzek, 1990). Furthermore, to come to meaningful conclusions about the development of energy efficiency in the German quarry industry, additional data taken from the cost structure survey, conducted by the Federal Statistical Office of Germany for the years 2003, 2007, 2010 and 2013, was analyzed (DESTATIS, 2005, 2009, 2012, 2015b).

On the basis of cluster analysis, the analyzed database was structured and particular reference operations were determined (cf. section 3). Through the compression of large amounts of data and concentration being placed on the most important properties, clustering reduces the required time and research expenditure while preserving a high quality of analysis (Kijewska & Bluszcz, 2016). The cluster analysis was performed by using the statistical software program "IBM SPSS Statistics" and the spreadsheet program "Microsoft Excel". Subsequently, through a qualitative examination of the cluster solution, the application potentials of belt conveyors in German quarries could be hypothesized (for details on the subject of cluster analysis see Backhaus, Erichson, Plinke, & Weiber, 2011; Hair, Black, Babin, & Anderson, 2010; Kijewska & Bluszcz, 2016).

3. Results

The results from the acquired data demonstrate that the total production of broken natural stones and carbonate rocks has decreased since the early 1990s by 15% from 320 Mt/a to 273 Mt/a in 2013 (BGR, 1997, 2000; Huy et al., 2014; Schwarzkopp et al., 2013). Significant changes in total production have not occurred since 2003 (Fig. 1). While the total production of broken hard-rock material has declined over the last twenty years, the average material produced per quarry remained almost constant over the same period (1990: 280 000 t per quarry; 2013: 270 000 t per quarry).

The average lease area per quarry slightly decreased from 24 ha to 20 ha. Similarly, the average number of levels per quarry decreased from 4 in 1990 to 3 in 2016. The mean bench height still remains at about 20 m (Braun & Hennig, 2016; Stoll et al., 1990).

Evaluation of the in pit process chain shows a nearly constant use of equipment. The material is still almost exclusively extracted by drilling and blasting and the loading is almost always realized by wheel loaders and excavators. Results of the study of Stoll et al. (1990) clearly show that fully mobile crushers were not used in 1990. Moreover, in 14% of all observed quarries, a combination of

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