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Development of a low-cost alternative for the monitoring of the ore hauling production indicators in small-scale mining

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Aos 06 dias do mês de dezembro de 2019, no(a) realizou-se a Defesa da Dissertação do(a) Senhor(a) Jaime Ijichi Machado, apresentada para a obtenção do título de Mestre intitulada:

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Após declarada aberta a sessão, o(a) Sr(a) Presidente passa a palavra ao candidato para exposição e a seguir aos examinadores para as devidas arguições que se desenvolvem nos termos regimentais. Em seguida, a Comissão Julgadora proclama o resultado:
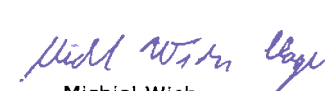
Nome dos Participantes da Banca	Função	Sigla da CPG	Resultado
Giorgio Francesco Cesare de Tomi	Presidente	EP - USP	APROVADO
Alizeibek Saleimen Nader	Titular	UFMG - Externo	APROVADO
Michiel Wichers	Titular	UNIFAL - Externo	APROVADO

Resultado Final: APROVADO

Parecer da Comissão Julgadora *

Eu, Elias Alves de Almeida _____, lavrei a presente ata, que assino juntamente com os(as) Senhores(as). São Paulo, aos 06 dias do mês de dezembro de 2019.

Alizeibek Saleimen Nader

Michiel Wichers

Giorgio Francesco Cesare de Tomi
Presidente da Comissão Julgadora

* Obs: Se o candidato for reprovado por algum dos membros, o preenchimento do parecer é obrigatório.

A defesa foi homologada pela Comissão de Pós-Graduação em _____ e, portanto, o(a) aluno(a) _____ jus ao título de Mestre em Ciências obtido no Programa Engenharia Mineral.

Presidente da Comissão de Pós-Graduação

I dedicate this work to my wife Michelle and my daughter Diana.

ACKNOWLEDGEMENTS

RESUMO

A mineração de pequeno e médio porte representa uma parte importante da economia mineral de um país. Essas empresas, apesar de representativas e numerosas, possuem baixo potencial de investimento em seu desenvolvimento por meio de novas tecnologias. Um dos problemas que as pequenas e médias empresas de mineração enfrentam é o controle de produção no transporte de minério. Esta operação sozinha pode representar até 60% do total do custo operacional devido ao consumo intenso de combustível e pneus, e representa mais da metade das emissões de gases de efeito estufa em uma pedreira. Visando este problema, esta dissertação pretende responder a seguinte pergunta: é possível monitorar a produção do transporte de minério em uma pequena mineração com um sistema de baixo custo? Os resultados mostraram que sim, é possível monitorar a produção de transporte de minério em uma pequena mineração com um sistema de baixo custo, utilizando hardware de prateleira, software de escritório e baixo uso de mão de obra. Os resultados foram validados em uma pedreira localizada no Estado de São Paulo, onde um sistema de US$ 480 apresentou resultados consistentes, melhorias na produtividade e redução na emissão de 33 t de CO_2 por ano.

Palavras-chave: mineração de pequena escala. transporte de minério. monitoramento de frota.

ABSTRACT

Small and medium-sized mining companies represent an important part of a country's mineral economy. These businesses, although representative and numerous, have low investment potential in their development through new technologies. One of the problems small and medium mining companies face is the ore hauling production monitoring. This operation alone can make as much as 60% of the total operating cost due to intense fuel and tires consumption and represents more than a half of the greenhouse gases emission in a quarry. Aiming at this problem, this document purposes to answer the following question: Is it possible to monitor the production of ore hauling in a small-scale mining with a low-cost system? The results showed that yes, it is possible to monitor the production of ore hauling in a small-scale mining with a low-cost system, using off-the-shelf hardware, regular office software and low use of labor. The results were validated in a quarry located in São Paulo State, where a US$ 480 system presented consistent results, improvements in productivity and reduction in emissions of 33 t CO_2 per year.

Keywords: small-scale mining. ore hauling. fleet monitoring.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANM	Agência Nacional da Mineração
Av	Availability
CC	Cycle Count
CEO	Chief Executive Officer
CLT	Cycle Loading Time
CLTT	Cycle Loaded Transport Time
CP	Crusher Point
CS	Unloading on the crusher Segment
CT	Cycle Time
CUPT	Cycle Unproductive Time
CUT	Cycle Unloading Time
CUTT	Cycle Unloaded Transport Time
D_{CP}	Distance between the point and the crusher point
D_{LP}	Distance between the point and the loading point
DNPM	Departamento Nacional de Produção Mineral
DOI	Diffusion of Innovation
E	Elevation
EPA	United States Environmental Protection Agency
FMS	Fleet Management System
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GLONASS	Globalnaya navigatsionnaya sputnikovaya sistema
GPS	Global Positioning System
ICT	Information and Communication Technologies
KPI	Key Performance Indicators
KRI	Key Result Indicators
LP	Loading Point
LS	Loading Segment
LTS	Loaded/Unloaded Transport Segment
M	Movement

MPi	Mine Productivity Index
OEE	Overall Equipment Effectiveness
P	Point
PI	Performance Indicators
PP	Performance
R	Proximity Radius
RI	Result Indicators
ROM	Run of Mine
RTLS	Real Time Location Systems
SD	Segment Distance
SEBRAE	Serviço Brasileiro de Apoio às Micro e Pequenas Empresas
SME	Small and Medium Enterprise
ST	Segment Time
T	Time
TOE	Technology, organization and Environment
TUM	Time Usage Model
U	Utilization
USB	Universal Serial Bus
USD	United States Dollar
UTM	Universal Transverse Mercator
V	Segment Speed
V_{tol}	Speed Tolerance
X	X position
Y	Y position

CONTENTS

1   INTRODUCTION

This work was conceived from the experience of the author in providing services in a small-scale mining company. The firm, a quarry[1], is a typical small-scale family-run business, being responsible for the employment and livelihood of some dozens of families and providing minerals for construction to the local market. The patriarch of the family says proudly "In the house of each one of this region has material from my quarry. The rock we extract here is part of the streets, schools, hospitals...". However, the costs are always a point of attention. The owner often tries to deploy some production control mechanisms based on manual annotations and reports that take a long time to process. This is because he has a certain aversion to the computer, in his office room there is only space on the desk for the old printing calculator.

He knows that one of the big cost drivers of the company is the ore loading and hauling activity, which is carried out by old diesel-powered dump trucks. He even looked at the market for a more modern solution for monitoring his trucks, but he was scared by both the complexity of the solutions and the price. This annoyed him, leading to the conclusion that these systems are only for large companies.

The reality of many small-scale mining companies is similar to that history. Companies of this size, although abundant and of great economic importance, have difficulties adopting new technologies to improve their processes.

Although with little technical knowledge but with great empirical expertise, the owner of the quarry where the application example of this work was conducted is correct when he states that the hauling operation is the one that represents the major part of the costs. May (2012) affirms that this operation alone can make up as much as 60% of the total operating cost.

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[1] According to the Institute of Quarrying (2020), the term "quarry" is often associated with a place where natural stone is extracted to produce principally construction material (aggregates). The term "mining" is generally associated with the extraction of metallic, industrial or coal minerals.

However, how is it possible for small-scale mining companies to obtain quality information about their operations? Is it possible to monitor the production of ore hauling in a small-scale mining with a simple low-cost system?

1.1 OBJECTIVES

The present dissertation aims to answer the following questions:
- What are the advantages of using technology in companies?
    - If there are competitive advantages, why do SMEs have difficulties in their implementation?
    - Is mining a low-tech industry? How does it compare with similar industrial sectors?
- What is the importance of mining today? What are the main operations and their impacts?
- How is it possible for small-scale mining companies to obtain quality information about their operations? Is it possible to monitor the production of ore hauling in a small-scale mining with a simple low-cost system?

The answer to the last question, which is the great question that moves this dissertation, it should not only present a solution but also present the results obtained in an example application in a real mining company.

1.2 DISSERTATION STRUCTURE

This dissertation is structured as follows:

- Chapter 1: Introduction to the topic of the dissertation, with the presentation of the questions that rules this work and the structure of the document.
- Chapter 2: Literature review aiming to answer the questions raised in the Introduction. The topics small and medium mining, technology use in companies, mining production chain, performance indicators, monitoring

systems and GPS are presented so that it is possible to have a knowledge base that takes the answer to the great question of this dissertation.

- Chapter 3: Materials and methods that are used to answer the great question of this dissertation. This chapter describes in detail the technology and logic used to design a low-cost system for monitoring the ore hauling production.
- Chapter 4: Results obtained in the application of the solution in a real mining company - application example.
- Chapter 5: Discussion of the results obtained in the application example and how the solution obtained answer the great question of the dissertation.
- Chapter 6: Conclusions and recommendations for future research.
- Chapter 7: Bibliographical references used in this work.

2   LITERATURE REVIEW

This chapter will present a bibliographic review necessary to understand the need and the importance of developing a simple and low-cost solution for monitoring the production indicators of ore hauling in small-scale mining companies.

Firstly, the relevance of small and medium-sized enterprises in the economy and their difficulties in investing in their development through technological management tools will be presented.

Then, it is necessary to characterize the operations of a mine and to verify the impact of the activity of ore transportation, both economically and in the environment. Demonstrating the relevance of this activity, it is important to verify the use of technology in mining. Is this a low-tech activity with little innovation, or is it a state-of-the-art industry? It is also relevant to address the impact on mining costs of the ore transportation operation, and how monitoring of this activity can be performed.

2.1   SMALL AND MEDIUM MINING

Small and medium enterprises (SMEs) are the most important sector in any country, corresponding to the great majority of companies, responsible for most jobs and economic activity (HILLARY, 2017).

According to extensive research conducted by Kozak (2007), SMEs are companies usually with a maximum number of employees ranging from 100 to 250. Enterprises classified as SME are estimated to account for at least 95% of registered firms worldwide. In Europe, for example, this number is well over 99% (WORLD BANK GROUP, 2009). According to Ayyagari et al. (2003), a research from a 55-country sample showed that SMEs (formal and informal) generate about 65-70% of GDP across all country income levels.

In Brazil, small companies alone accounted for 99% of companies and for 54% of formal jobs in 2016 (SERVIÇO BRASILEIRO DE APOIO ÀS MICRO E PEQUENAS

EMPRESAS, 2018). According to this survey, the companies were classified according to the classification presented in Table 1.

Table 1 – Classification of companies according to size.

| COMPANY SIZE | SECTORS | |
	INDUSTRY	TRADE AND SERVICES
Micro	up to 19 employees	up to 9 employees
Small	from 20 to 99 employees	from 10 to 49 employees
Medium	from 100 to 499 employees	from 50 to 99 employees
Large	more than 500 employees	more than 100 employees

Source: Translated from SERVIÇO BRASILEIRO DE APOIO ÀS MICRO E PEQUENAS EMPRESAS, 2018.

Similarly, small-scale mining enterprises are very representative, mainly in terms of the number of people employed (HENTSCHEL; HRUSCHKA; PRIESTER, 2002). In Brazil, small and medium-sized mining companies correspond to 95% of the mines (ANUÁRIO MINERAL BRASILEIRO, 2010).

In the same way that there are several methods that one can classify a company in small, medium or large, each of which may lead to a different classification (TERENCE, 2008), in mining there is no single criteria to classify the size of the company. In developing countries, governmental organs define small mining companies as individuals, groups, families or cooperatives with no or little mechanization (HENTSCHEL; HRUSCHKA; PRIESTER, 2003). In a more quantitative way, the United Nations (BUGNOSEN, 2006) defines small mining as "any mining operation with annual production of raw material of 50,000 t or less".

In Brazil, the *Departamento Nacional de Produção Mineral* - DNPM (nowadays called *Agência Nacional da Mineração*-ANM[2]) classifies mining companies according to its annual gross production of Run of Mine (ROM). According to this classification it is possible to define a small mining company as the one with gross annual production of

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[2] Mining Federal Agency responsible for regulating mining in Brazil.

up to 100,000 t and medium mining company as the one with up to 1,000,000 t (ANUÁRIO MINERAL BRASILEIRO, 2010).

2.2   TECHNOLOGY

Although small and medium companies are numerous, it is not easy for them to access new technologies. According to Silva (1998) small and medium-sized enterprises have difficulty investing in their development, since their investment potential is low compared to large companies.

Other authors (DEWAN; RIGGINS, 2005; BACH; ZOROJA; VUKŠIĆ, 2013) argue that small and medium-sized enterprises have the least access to Information and Communication Technologies - ICT. This digital exclusion can be divided into two categories (DEWAN; RIGGINS, 2005): first-order digital exclusion, related to the difficulty or impossibility of access to the technology; and second order digital exclusion, related to difficulties in the use of technology and obtaining relevant results with this technology.

The assimilation of new technologies is a challenge for this type of company, particularly family companies that use the same methods and processes for several generations. Another factor is when the company does not have a skilled workforce that is able to assimilate and adapt new knowledge and technologies to local conditions (UNITED NATIONS, 2005).

In contemporary business world, companies rely on ICT to support strategic thinking (CARR, 2003). Investments in this kind of technology are a competitive necessity if firms are willing to compete in the globalized world (BARCLAY; DUGGAN, 2008; WORLD ECONOMIC FORUM, 2010).

There is significant consensus that ICTs have major effects on the productivity, organizational expansion, profitability and competitiveness of SMEs (MARTINS; RAPOSO, 2005; RAYMOND; BERGERON; BLILI, 2005; CONSOLI, 2012; TAYLOR,

2013). Knowing that the use of technology brings many benefits to the company, a question should be answered: Is mining a high-tech industry?

There are examples of state-of-the-art technology being used in large mining companies. Rio Tinto has implemented innovative systems in its mines to increase the efficiency of processes, such as autonomous ore transport equipment and new sorting systems, capable of separating the gangue even before the material reaches the beneficiation (RIO TINTO, 2014). Newmont Mining Corporation has presented very satisfactory results integrating the geology and geostatistics systems with the operation (SCHUTZ, 2006). VALE started the test with autonomous trucks in the Brucutu mine (municipality of São Gonçalo do Rio Abaixo in Brazil) in January 2018 with positive results (VALE, 2018).

Bartos (2007) tried to answer the question raised in his study. The author concluded that this sector is a great user of sophisticated technologies, as presented in the previous paragraph. And that, excluding industries focused on the development of high technology, mining has the same level of innovation as other industries. Nevertheless, he also concludes that the use of sophisticated technologies is more restricted to large mining companies.

Cutifani (2013)[3] however claims that the mining industry could invest more in innovation. He also states that the mineral industry should be more collaborative and have as its goal the improvement of its relationship with society.

Knowing that mining is not a less technological sector than other industrial sectors, one must then investigate why the adoption of new technologies is so complicated in SMEs. In this context, Taylor (2015) explored this theme using two theoretical models to explain ICT adoption by SMEs: the Diffusion of Innovation (DOI) theory by Rogers (1995) and the Technology, Organization and Environment (TOE) framework by Tornatzky and Fleisher (1990) to propose and integrated theoretical model of ICT adoption in SMEs. Oliveira and Martins (2011) elaborated a literature review about the

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[3] Mark Cutifani, CEO of Anglo American plc since 2013.

ICT adoption models, giving greater emphasis to the two theories (DOI and TOE), since those models are the most prominent and relevant at the firm level.

The integrative model proposed by Taylor (2015) selected the key factors influencing the ICT adoption by SME, dividing them into internal and external factors. The internal factors are entrepreneur/CEO characteristics, organizational culture, structure and resources, relational complexities (e.g. family involvement in the SMEs operation), and ICT awareness, knowledge and know-how of staff. The external factors are business networks, trading partners, industry type, service providers, ICT consultants and vendors, government support and policies, economic and competitive pressures, and types of ICT products in the marketplace. Figure 1 shows the proposed model.

Figure 1 – Integrated model of factors influencing ICT adoption decisions in SMEs.
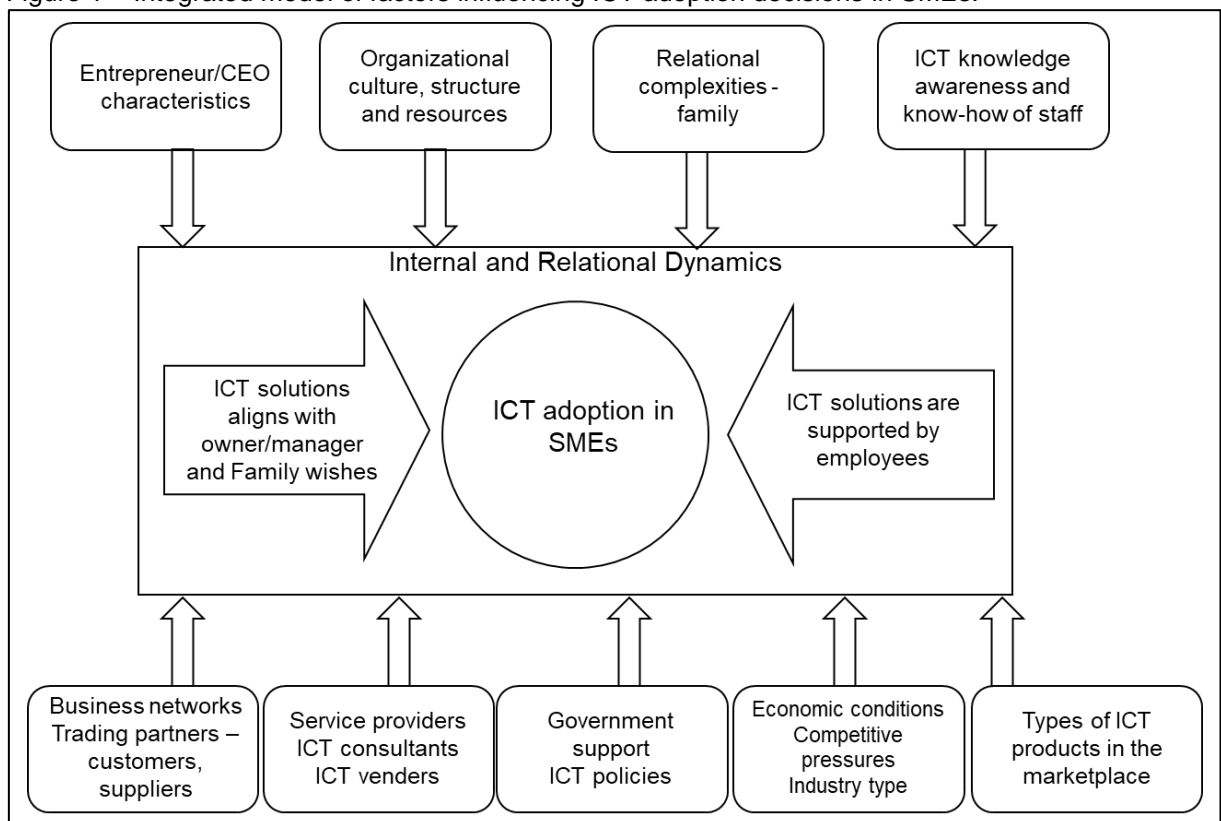
Source: Taylor (2015).

Giotopoulos et al (2017) conducted a similar study, joining the DOI and TOE models and using a large database of Greek SMEs. The data revealed that convincing the leaders and owners of SMEs about the advantages of long-term adoption of new technologies is an important step, since the adoption requires investment in training

and deployments. Another important point is the level of education of workers, the higher the skills, the easier it is to assimilate new technologies.

2.3   MINING PRODUCTION CHAIN

The mining industry plays a crucial role in ensuring an acceptable quality of life to billions of people across the globe, and technological discoveries are needed to improve the minerals and energy processes, from extraction of resources to their use and reuse (MORAN et al, 2014). This activity is one of the oldest of mankind, and the natural resources that have been mined have conditioned the economic and civilizational development of societies (DUBIŃSKI, 2013).

Modern mining extract resources which are used to fulfill the need of human beings, like energy, construction, chemical, pharmaceutical, automotive, electronics; and the extraction of resources continues to increase, as shown in Figure 2 (LUTTER; GILJUM; GÖZET, 2018).

Figure 2 – Domestic extraction of the world in 1970-2017.
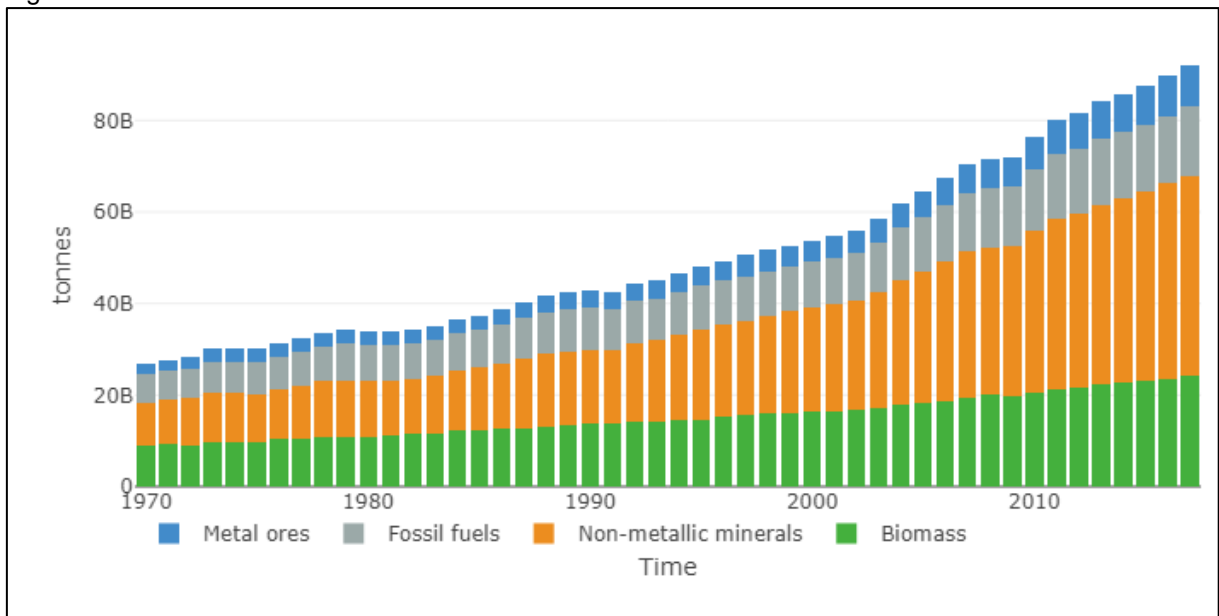
Source: LUTTER; GILJUM; GÖZET, 2018.

Figure 2 stands out the great growth of non-metallic minerals, such as industrial minerals and civil construction.

In Brazil, according to Sumário Mineral 2016 (2018), during the year 2015 the mineral industry had a participation of 2.1% in GDP, corresponding to US$ 32.5 billion, and directly employed 209,500 people. The country has the world's main reserves of niobium and manganese, as well as important reserves of tantalum, graphite, iron ore, barite, rare earths, among others (Figure 3); being responsible for 93.7% of the world production of niobium and 13% of iron production (Figure 4).

Figure 3 – Brazilian participation (%) in the world's mineral reserves in 2015.
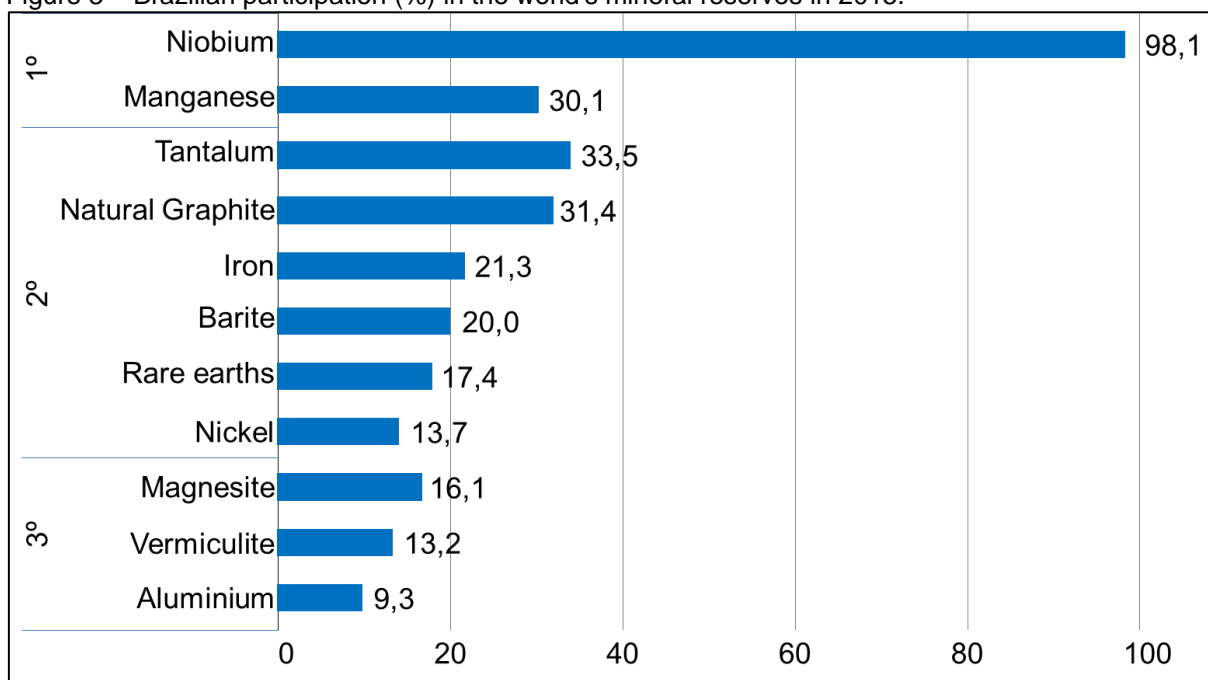
Source: Translated from SUMÁRIO MINERAL 2016 (2018).

Figure 4 – Brazilian participation (%) in the world ore production.
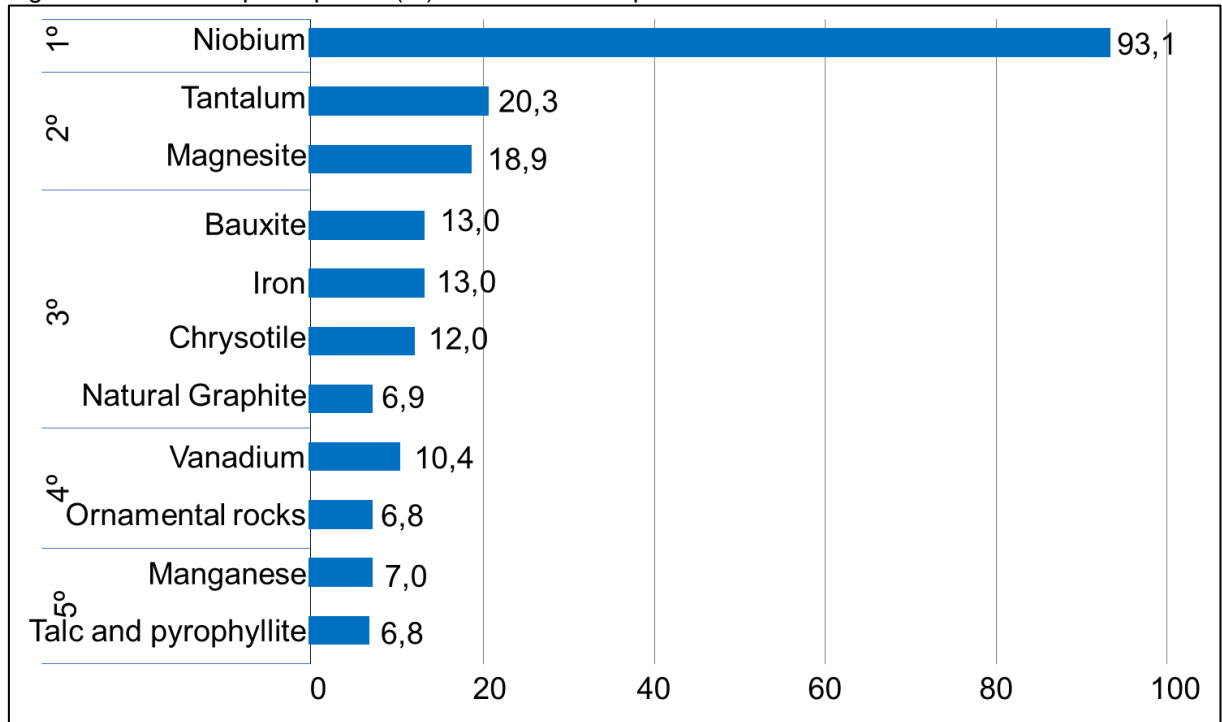
Source: Translated from SUMÁRIO MINERAL 2016 (2018).

A general mine operation (open pit or underground) consists of drilling, ore fragmentation, loading and hauling the material to a dumping location where the material will either be stored or further processed (MAY, 2012). In surface mines, the haulage is usually executed by trucks, and this operation represents as much as 50%-60% of the mining operating cost. (KENNEDY, 1999; BOZORGEBRAHIMI, 2004; THOMPSON, 2005; ERCELEBI; BASCETIN, 2009; TOPAL; RAMAZAN, 2010; NEL; KIZIL; KNIGHTS, 2011).

Haulage operating costs are considerable due to intense fuel and tires consumption (RODOVALHO; LIMA; DE TOMI, 2016). In addition, this operation contributes with more than half of the emission of greenhouse gases in a quarry (KITTIPONGVISES; CHAVALPARIT; SUTTHIRAT, 2016).

Shovel-truck systems are the most common in open-pit mining (ERCELEBI; BASCETIN, 2009), corresponding to 95% of the global surface mining fleet due to their flexibility and economy of scale (DE LEMO PIRES, 2013). The shovel-truck cycle consists of 4 phases:

1. Shovel loading the trucks;
2. Loaded truck travel from loading area to dump location;
3. Truck dumping the ore on dump location;
4. Empty truck travel from dump location to loading area.

Figure 5 shows a schematic of a typical truck-shovel operation from loading area to dump location (ore or waste).

Figure 5 – Schematics of Truck–Shovel Operation.
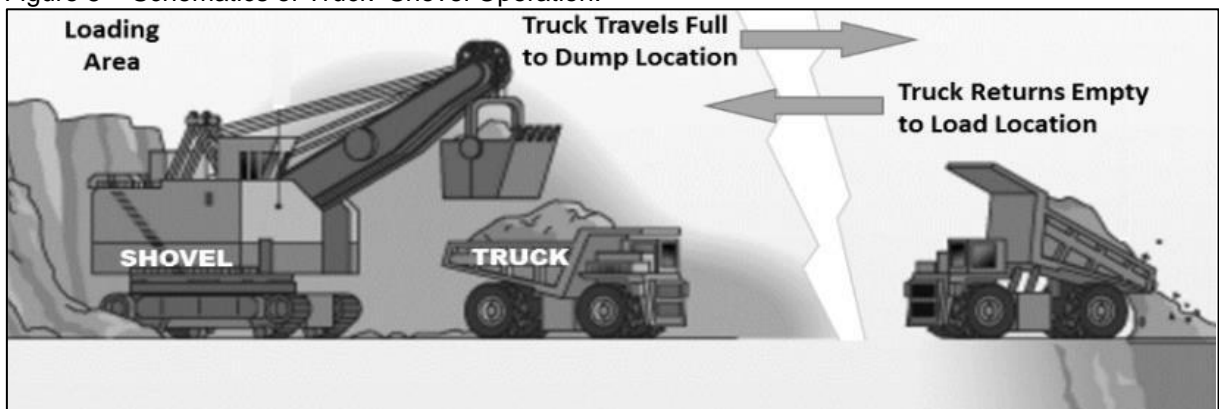
Source: Dzakpata et al. (2016).

The interaction among the randomness of interarrival times of those 4 phases results in either trucks to queue at the shovel or the shovel being idle while waiting for a truck to arrive (ELBROND, 1990), which are both non-productive periods. The monitoring of those times is important to analyze the operation productivity.

Haulage performance indicators monitoring is nothing new for large mines. In their article, Rodovalho, Lima and De Tomi (2016) studied the performance indicators and the variables related to fuel consumption of mining trucks. Using statistical analysis and mathematical modeling tools to identify the operational variables that influence the fuel oil consumption of haul trucks it was possible to reach a 10% reduction of diesel consumption. According to the article, the study was carried out in a large iron mining in the Quadrilátero Ferrífero (Brazil).

However, as stated before, it is difficult for smaller sized companies to adopt technologies in order to help the monitoring of these indicators in a small or medium

mining company. Starting to monitor the most representative cost driver – hauling operation, should bring a huge impact both economically and environmentally. Monitoring such a supply demanding operation is the key for the reduction of greenhouse gas emissions (LEVESQUE; MILLAR; PARASZCZAC, 2014).

2.4 GREENHOUSE GAS EMISSIONS

According to Easterbrook (2016), greenhouse gas – GHG is a gas that absorbs and emits infrared radiation. The primary greenhouse gases in the atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Those gases are vital in sustaining a habitable temperature for the planet. It has been estimated that without these gases, the average surface temperature of the Earth would be about -18°C (QIANCHENG, 1998).

However, since the Industrial Revolution energy-driven consumption of fossil fuels has led a rapid increase in CO_2 emissions, leading to a planetary warming impact. This global warming can lead to ecological, physical and health impacts, including extreme weather events (such as floods, droughts, storms, and heatwaves); sea-level rise; altered crop growth; and disrupted water systems (RITCHIE; ROSER, 2019).

Figure 6 shows the global average land-sea temperature relative to the 1961-1990 average temperature baseline. Figure 7 shows the Global average concentration of carbon dioxide in ppm.

Figure 6 – Global average land-sea temperature relative to the 1961-1990 average temperature baseline.
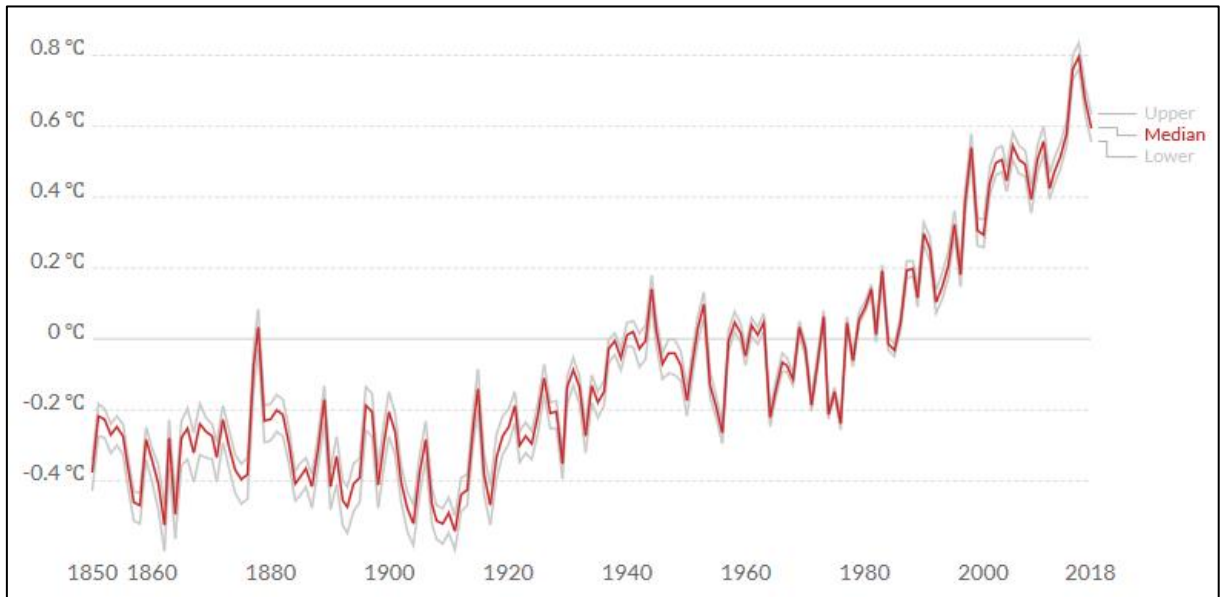
Source: RITCHIE; ROSER, 2019.

Figure 7 – Global average concentration of carbon dioxide in ppm.
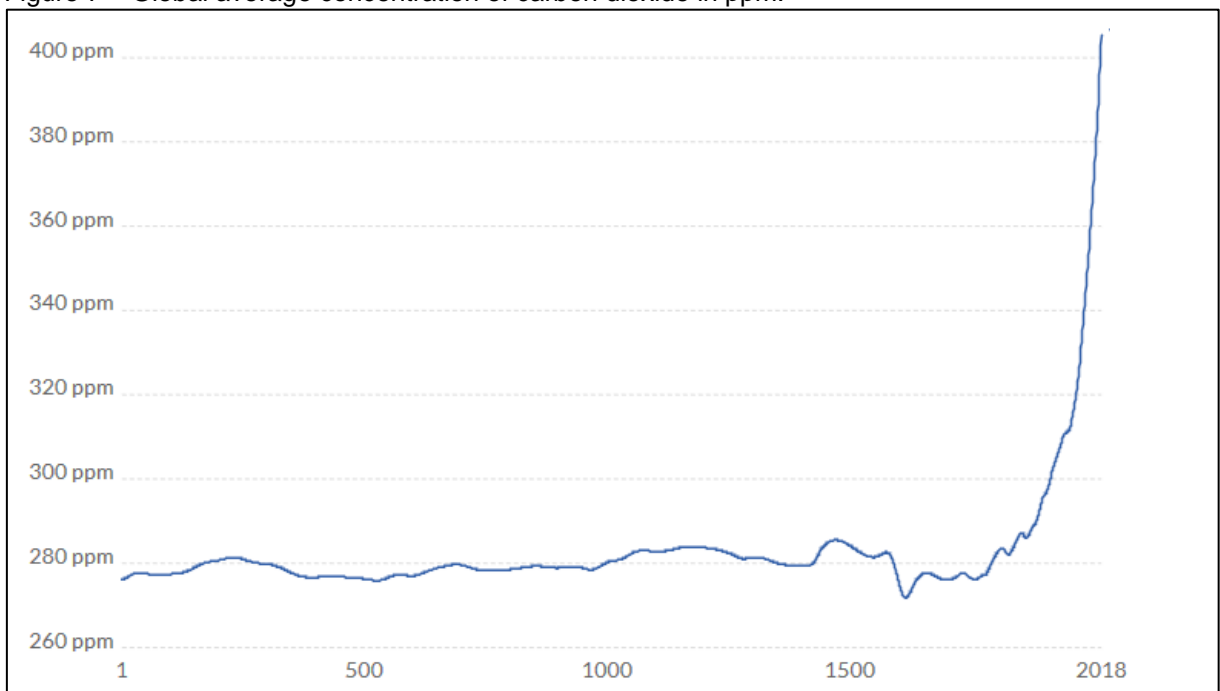
Source: RITCHIE; ROSER, 2019.

Mining operations are intensive energy consumers (KAARSBERG; HUANGFU; ROOP, 2007), and hauling equipment is generally powered by diesel engines which are also responsible for the emission of GHG into the atmosphere (NORGATE; HAQUE, 2010, 2012).

To mitigate the effects of global warming, various countries have requested controls and limits in the emissions of GHGs (MEINSHAUSEN et al, 2009), and according to the US Department of Energy (2007) mining companies have potential to save about 61% of their energy consumption by improving the efficiency of operations.

2.5   PERFORMANCE INDICATORS

Performance indicators are measures of different aspects of organizational performance that are most crucial for the current and future success of the organization (AUSINDUSTRY, 1995). Parmenter (2015) affirms that many companies are working with wrong measurements, most of them calling those measurements incorrectly as "Key Performance Indicators" – KPI. According to him, there are 3 types of performance measures and many organizations use an inappropriate mix of these indicators:

1. Key result indicators (KRIs) tell you how you have done in a perspective;
2. Performance indicators (PIs) tell you what to do;
3. KPIs tell you what to do to increase performance dramatically.

Availability and utilization are very important performance indicators of equipment and are a usual tool for decision-making by management in the mining operation, since rate of production is highly sensitive to those indicators (RAI, 2004; OSANLOO, 2005; BARABADY, 2007; DHILLON, 2008). Figure 8 shows a Time Usage Model (TUM) commonly used across the mining industry.

Figure 8 – Time Usage Model (TUM) commonly used in the mining industry.

Source: MUCHIRI; PINTELON, 2006; JEONG; PHILIPS, 2001.

One of the most commonly used measures of equipment efficiency is the Overall Equipment Effectiveness – OEE (EMERY, 1998; MOHAMMADI; RAI; GUPTA, 2015) and is defined by Equation 1.

$$OEE = Availability \times Performance \times Quality$$

Equation 1

Where:

Availability = Operating time / Planned Production time;

Performance = (Output / Operating time) / (Rated output / Design Cycle time);

Quality = Valuable output / Total Output.

Another common indicator for mining equipment is the Mine Productivity Index – MPi (LEE; JOHNSON, 2015; LANKE; HOSEINIE; GHODRATI, 2014).and is defined by Equation 2.

$$MPi = Av^a \times PP^b \times U^c$$

Equation 2

Where

Av = Availability;

PP = Performance;

U = Utilization;

0<(a, b, c)<=1 and a + b + c=1.

2.6   FLEET MONITORING SYSTEMS

As presented in the previous item, time monitoring is the basis of performance indicators. There are many companies that offer solutions for the monitoring of mining equipment. Looking for the words "mining fleet monitoring" on Google gets about 11 million results. The first page shows 7 different companies that offer mining fleet monitoring products or services. The Table 2 lists the names of these companies and their country of origin.

Table 2 – List of mining fleet monitoring companies found on Google first page.

COMPANY	PAGE TITLE	PAGE DESCRIPTION	COUNTRY OF ORIGIN
Orbcomm	Mining: Fleet Tracking and Management | ORBCOMM	By combining real-time location systems (RTLS), cellular, satellite and other technologies, ORBCOMM's fleet and underground mine tracking solutions provide operators the insight they need to maximize mine production and profitability, no matter how remote.	USA
Hexagon Mining	Fleet Management | Hexagon Mining	Track and monitor trucks, dozers, shovels, drills, and more.	USA

Table 3 – List of mining fleet monitoring companies found on Google first page (continued).

COMPANY	PAGE TITLE	PAGE DESCRIPTION	COUNTRY OF ORIGIN
Wenco	Wencomine Fleet Management System	Work with experts to get support, insights, and solutions to optimize production, safety, profit — and even equipment life. ... Wencomine fleet management streamlines equipment assignment, payload control, and dispatch, helping you get more out of your mine.	Canada
Modular mining	DISPATCH Fleet Management System - Modular Mining	The DISPATCH® Fleet Management system (FMS) revolutionized the way mines work in real-time, optimizing the production process to increase tonnage	USA
Chevin	Mining Fleet Management Software - Increase Efficiency | Chevin	Chevin's fleet management software for mining allows you to store data on secure, remotely-accessible servers – providing flexibility and real-time knowledge of what's happening within your company at any time.	Australia

Table 2 - List of mining fleet monitoring companies found on Google first page (continued).

COMPANY	PAGE TITLE	PAGE DESCRIPTION	COUNTRY OF ORIGIN
SNC	Mine Fleet Management System – SatNetCom	Increase Production. Reduce Cost. Improve Business Intelligence. Real-Time KPI's and Reporting. Mine Fleet Management System	Indonesia
Ctrack	Mining Sector Fleet Management Solutions | Ctrack Global	Ctrack Mining utilizes a specific range of remote monitoring systems to alert control room staff to vehicle abuse and driver behavior, helping to safeguard against accidents and ensuring maximum efficiency and productivity.	South Africa

Source: Personal file.

Analyzing the data, it is noticed that many of these are large companies specializing in delivering tailored and complex solutions to large mining companies, most of which come from developed countries.

2.7 GLOBAL POSITIONING SYSTEM - GPS

Mining fleet monitoring systems utilize positioning sensors to track the supervised objects. Global Positioning System (GPS) is the most used, it was developed by the United States Department of Defense in the early 1970s (LI; HAN; SHEN, 2002). With this system it becomes possible to obtain the position of the receiver in a continuous way and under any climatic conditions (GROVES; KECOJEVIC; KOMLJENOVIC, 2007).

According to the U. S. Air Force (2013), the System consists of a constellation of 24 satellites flying 20,350 km above the surface of the earth. Each one circles the planet twice a day in one of six orbits to provide continuous, worldwide coverage. In a

simplified way, the position of an object on earth can be determined geometrically by the estimated distance between this object and at least 4 satellites with known position. This distance is calculated by the time the radio signal takes from its emission on the satellite to the reception in the GPS sensor installed on the object. The accuracy of the GPS system depends on a number of factors, such as satellite signal blocking by buildings or relief, interference with radio signals, solar storms, number of visible satellites, etc. Figure 9 shows an illustrative diagram of how the system works.

Operating similar to GPS, the GLONASS (*Globalnaya navigatsionnaya sputnikovaya system*) was developed by the Soviet Union during the Cold War. It also uses a constellation of 24 satellites in a 12-hour orbit. Separately, GPS and GLONASS present similar results in terms of accuracy. But using the satellite constellation of the two systems together yields much more accurate results, especially using the combined system in mining areas, where benches often block the reception of satellite signals (JOHNSON, DIGGELEN, 1998). This is especially interesting in mining operations where the slopes can disrupt or block satellite signals.

In addition to GPS and GLONASS, there are other global navigation satellite systems, such as Beidu Navigation Satellite System – BDS (China), Galileo (European Union), Indian Regional Navigation Satellite System – IRNSS (India) and Quasi-Zenith Satellite System – QZSS (Japan) (GPS: THE GLOBAL POSITIONING SYSTEM, 2017).

The use of GPS has become an essential component in large mining for tracking mobile equipment, accurate positioning of excavators, trucks and other equipment (RAMANI, 2012).

Figure 9 - Explanation diagram of GPS operation.

1 GPS satellites broadcast radio signals providing their locations, status, and precise time $\{t_1\}$ from on-board atomic clocks.

2 The GPS radio signals travel through space at the speed of light $\{c\}$, more than 299,792 km/second.

3 GPS device receives the radio signals, noting their exact time of arrival $\{t_2\}$, and uses these to calculate its distance from each satellite in view.

4 Once a GPS device knows its distance from at least four satellites, it can use geometry to determine its location on Earth in three dimensions.

To calculate its distance from a satellite, a GPS device applies this formula to the satellite's signal:

distance = rate x time

where rate is $\{c\}$ and time is how long the signal traveled through space.

The signal's travel time is the difference between the time broadcast by the satellite $\{t_1\}$ and the time the signal is received $\{t_2\}$.

Source: Adapted from U. S. AIR FORCE, 2013.

2.8 LITERATURE REVIEW INSIGHTS

From the Literature Review chapter, it is possible to conclude:

- Small and medium enterprises are very important for a country's economy, corresponding to most of the companies, responsible for most of the jobs and more than a half of GDP. In Brazil this picture is not different;
- In the same way, small scale mining companies correspond to the largest share of mineral extraction enterprises;
- The use of technology in companies brings benefits, such as higher productivity, organizational expansion, profitability and competitiveness. However, it is known that SMEs have difficulties with the assimilation of new technologies due to the company's leaders and owners lack of innovation knowledge, workers level of education and difficulty on investing in this kind of subject;
- In order to analyze if the mining sector is a low-tech industry, it was concluded that large mining companies are great users of sophisticated technologies, and it has the same level of innovation as other industries.
- Mining is a crucial segment for the human development, and the mineral extraction have been raising to follow the needs of the population. Brazil is an important player in the world mining industry, with important mineral reserves and a representative production share;
- Mining is an intense consumer of resources, such as diesel and tires for ore haulage. This operation also represents more than a half of the mining operating cost;
- There is great potential for energy economy in the mining industry. By improving processes it is possible to affirm that there is a possibility of reducing the emission of large quantities of GHGs, and consequently the saving of natural and financial resources;
- The performance indicators are crucial for the healthiness of a corporation, tells the staff what to do to increase performance;
- Performance indicators for equipment have in common the measurement of the time in which the equipment is being productive;

- There are several companies around the world that offer solutions for monitoring mining equipment. Most of them from developed countries and are used to provide solutions to large mining companies;
- The use of GPS technology is essential in large mining sites, being able to provide the positioning of equipment accurately;
- It is difficult for smaller mining companies to adopt new technologies to capture, manage and analyze data to follow up the operation performance indicators.

From the research carried out in the literature review, the questions arise: how is it possible for small-scale mining companies, with difficulties in implementing technologies to monitor equipment and lack of skilled labor, to obtain this type of quality information? Is it possible to monitor the production of ore hauling in a small mining with a simple low-cost system?

3 MATERIAL AND METHODS

To answer the question posed in the previous item the idea is to keep the solution simple, using whenever possible off-the-shelf hardware, regular software normally used in offices and minimizing the need for the use of labor.

For validation, the proposed method was tested in a quarry located in São Paulo State in the form of an application example. Figure 10 shows aerial photography of the quarry. The pit has its largest dimension of 500 meters and 180 meters wide, and the processing plant occupies an area of approximately 10,000 m².

3.1 DESCRIPTION OF THE QUARRY

The quarry produces material for civil construction and is a typical medium sized Brazilian mining company, with 600,000 t annual ROM production, around 40 employees, familiar managed business and no production control system. The only consistent information that is recorded is the mass of rock that is sold. This is because all mining in Brazil are obliged to issue the invoices through the measurement via truck scale, which must be calibrated periodically. All other production information, such as daily production, equipment availability and utilization, are estimated from manual annotations.

The process begins with the rock drilling through hydraulic drill (Figure 11). The holes are loaded with explosives for rock fragmentation, which is then loaded onto the trucks by hydraulic excavators (Figure 12). The hauling trucks travel an average distance of 1,000 meters to the dumping location, and the difference between loading and unloading area altitudes is approximately 80 m. Figure 13 shows an overview of the application example mining site.

Figure 10 – Aerial photography of the quarry.

Source: Personal file (Drone photography taken in August 2018).

Figure 11 – Rock drilling in the application example.

Source: Personal file (Photo taken in March 2018).

Figure 12 – Ore loading operation.
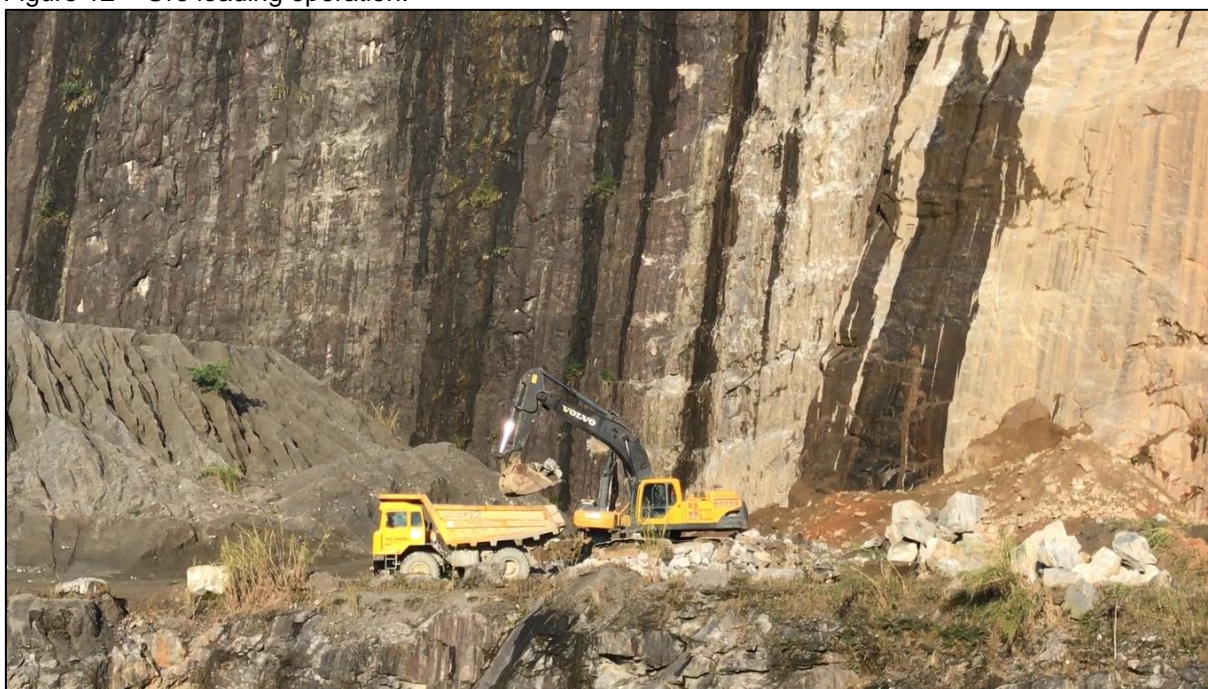
Source: Personal file (Photo taken in August 2018).

Figure 13 – Application example mining site overview.

Source: Personal file (Photo taken in January 2018).

The processing of ROM to produce civil construction material is basically composed of 3 stages of crushing and screening processes to separate the crushed stone by granulometric fraction. Figure 14 shows an overview of the crushing plant.

Figure 14 – Overview of application example crushing plant.

Source: Personal file (Photo taken in November 2017).

The quarry produces gravel according to the granulometric distributions required by the construction industry for each type of use, as presented in Table 4. This final product is loaded onto the client's trucks by wheel loader, and the weight of each truck is measured at the entrance and exit for issuing the invoice.

Table 4 – Quarry products and their respective uses.

COMMERCIAL NAME	SIZE DISTRIBUTION	COMMON USE
Very fine gravel (*Pó*)	0 - 4.8 mm	Asphalt plants, precast parts, mortar
Crusher run (*Bica corrida*)	0 – 50 mm	Asphalt base
Fine gravel (*Pedrisco*)	4.8 – 9.5 mm	Beams, pre-cast slabs, interlocking floors, pipes, bricks, slabs and finishes
Medium gravel (*Brita 1*)	9.5 – 19 mm	Most used gravel in construction. Manufacture of concrete, beams, slabs
Coarse gravel (*Brita 2*)	19 – 25 mm	Manufacture of concrete with more strength. Foundations and floors of greater thickness;
Very coarse gravel (*Brita 3*)	25 – 50 mm	Track ballast for railroad ties
Cobble (*Rachão*)	Up to 300 mm	Drainage works, rockfill

Source: Personal file.

Auxiliary services such as road maintenance are carried out by wheel loaders and a water truck is responsible for dust control. The maintenance of mobile equipment is

carried out by a maintenance truck. Table 5 shows a list of the main equipment of the quarry.

Table 5 – Main equipment list.

DESCRIPTION	QUANTITY	POWER PER UNIT (kW)	SUPPLY
Hydraulic rock drill	1	170	Diesel
Hydraulic excavator	3	240	Diesel
Haul truck	4	260	Diesel
Wheel loader	2	220	Diesel
Water truck	1	150	Diesel
Maintenance truck	1	150	Diesel
Jaw crusher	1	150	Electricity
Cone crusher	2	220	Electricity
Screen	2	45	Electricity

Source: Personal file.

The power of diesel engines totals 2,670 kW, even though the application example is a medium scale quarry.

3.2 GPS SENSOR

By "off-the-shelf" hardware it is understood that it should be easily found and purchased on the market. For the study a Garmin etrex 30X Portable GPS was acquired. The equipment was purchased in November 2017 for US$ 370 (Nov 2017 currency). Figure 15 shows the picture of the purchased equipment.

Figure 15 – Garmin Etrex 30X.

Source: Personal file (Photo taken in June 2018).

Among its specifications, the equipment has the following highlights (GARMIN, 2018):

- High sensitivity GPS receiver with GLONASS support: when acquiring information using both GPS and GLONASS it is expected that the data will be more accurate, and that position information can be obtained even at pit bottom;

- 3-Axis Compass: Truck direction information can be collected regardless of the position the GPS device is installed in the truck, whether horizontally, vertically or simply supported on the panel;

- Barometric Altimeter: With the altitude information being acquired through the barometric altimeter, it is easier to define when the truck is going up or down the pit;

- GPX Track file recording;

- Data download via USB port and export in CSV format.

This sensor is installed inside the truck for data acquisition during the hours of operation.

3.3 SPREADSHEET APPLICATION

For processing and analysis of the obtained data, a standard spreadsheet software was used. This study used the Microsoft Office 365 package. It was chosen for being one of the most popular in the world, being used by more than 1 billion users (ARGHIRE, 2012).

Office 365 is a subscription service that brings together the company's traditional office programs (Word, Excel and Power Point) with other cloud tools such as storage and information sharing (MICROSOFT, 2018). Annual subscription plans start at US$ 9.00 per month for each user.

3.4 DESCRIPTION OF THE PROPOSED SYSTEM

The GPS sensor is placed in the ore transport truck and collects positioning data during the operation. The data obtained is downloaded via USB cable at the end of the day, exported to a spreadsheet file format (CSV) and inserted into the spreadsheet software. The data is then treated, analyzed and the indicators are calculated automatically. The results can be made available in the cloud for company management access on any type of platform: mobile, tablet or computer.

Figure 16 shows a diagram of the proposed system.

Figure 16 – Diagram of the proposed system.

Data collect

- GPS installation on the truck
- Collection of data during operation
- Extraction of collected data

Processing and analysis of data

- GPS data processing
- Segment identification
- Data analysis

  - Loading Segment [LS_n]
  - Unloading on the Crusher Segment [CS_n]
  - Loaded/Unloaded Transport Segment [LTS_n]

  - Cycle Time [CT_j];
  - Loading Time [CLT_j]
  - Unloading Time [CUT_j]
  - Loaded Transport Time [$CLTT_j$]
  - Unloaded Transport Time [$CUTT_j$]
  - Unproductive Time [$CUPT_j$]

Results

- Making results available

Source: Personal file.

3.4.1 Data collection

Data collection is performed through the GPS sensor installed in the truck. The data must be saved in a track file to be exported to a computer where it will be processed.

Thus, the sensor should only collect the data. All processing will be performed on a computer equipped with a spreadsheet application. As there will be no data processing on the sensor, a simple GPS sensor with little or no customization can be used.

With the advancement and popularization of platform for developers like Raspberry or Arduino, it would be possible to integrate the sensor directly with the computer through a wireless connection and applications in a cloud server. A mobile app could also be developed. So, it would be possible to broadcast live the positioning of the truck.

To keep the solution simple and at the lowest possible cost, in the application example the Garmin Etrex 30X portable GPS was used, and data was transmitted manually to the computer via USB cable.

In order to record the average consumption of diesel, the daily fuel supply of the trucks was also monitored by checking the liters of diesel that were fueled in each truck.

3.4.2 Data processing

As previously stated, the processing of data generated from the GPS sensor is performed in Microsoft Excel. However, processing can be performed in any program that accepts logical data manipulation.

In the application example the chosen GPS sensor generated a track file during the truck data collection. The relevant information recorded in the track file is displayed in Table 6.

Table 6 – Track file.

Point ID	Elevation (m)	Segment distance (m)	Segment time	Segment speed (km/h)	Time	X position (m)	Y position (m)
P_1	E_1	SD_1	ST_1	V_1	T_1	X_1	Y_1
P_2	E_2	SD_2	ST_2	V_2	T_2	X_2	Y_2
P_3	E_3	SD_3	ST_3	V_3	T_3	X_3	Y_3
P_n	E_n	SD_n	ST_n	V_n	T_n	X_4	Y_n

Source: Personal file.

Description of the data collected:

- Point ID [P_n]: Increasing numbering that identifies the point;
- Elevation [E_n]: Elevation obtained from the barometric sensor in meters;
- Segment Distance [SD_n]: Geometric distance between the points P_{n+1} and P_n, given by Pythagorean Theorem (Equation 3) in meters;

$$SD_n = \sqrt{(Y_{n+1} - Y_n)^2 + (X_{n+1} - X_n)^2}$$

Equation 3

- Segment Time [ST_n]: Time between the moment that P_{n+1} and P_n was collected (Equation 4);

$$ST_n = T_{n+1} - T_n$$

Equation 4

- Segment Speed [V_n]: speed of the truck during the segment, given by the Segment Distance [SD_n] and the Segment Time [ST_n] (Equation 5) in km/h;

$$V_n = \frac{SD_n}{ST_n}$$

Equation 5

- Time [T_n]: Time that the point P_n was collected (including date information – dd/mm/yyyy hh:mm:ss);
- X position [X_n]: Geographic UTM longitude in meters;
- Y position [Y_n]: Geographic UTM latitude in meters;

The spreadsheet program should then automatically define the sections of interest for data analysis: Loading Segments, Loaded Transport Segments, Unloading on the Crusher Segment, Unloaded Transport Segment.

Following will be presented the logic used in the spreadsheet program. Simple type functions will be used "IF, THEN, ELSE, AND, >, <, =" so that it is not given preference for any programs or sort of programming language.

3.4.2.1 System elements

In order for the spreadsheet program to be able to classify the segments, it is first important to define some parameters:

- Loading Point [LP]: geographic point in UTM where the truck should be loaded. This data will be represented as $[LP] = (LP_x, LP_y)$, being LP_x the longitude in meters, and LP_y the latitude in meters;

- Crusher Point [CP]: geographic point in UTM where the crusher is installed. This data will be represented as $[CP] = (CP_x, CP_y)$, being CP_x the longitude in meters, and CP_y the latitude in meters;

- Proximity Radius [R]: Radius in meters which defines the area around the loading point [LP];

- Speed Tolerance [V_{tol}]: Minimum velocity for a movement to be considered. This is necessary because of the sensor error. For instance, if the error of the sensor is 5 m and 2 points were collected within 1 second difference, the truck even stopped can present in the collected data a speed greater than zero due to the error between the points collected;

- Movement [M_n]: checks if the truck is moving, following the logic:

$$\text{IF } V_n > V_{tol}, \text{ THEN } [M_n] = 1, \text{ ELSE } [M_n] = 0$$

When $[M_n] = 1$, the truck is moving, when $[M_n] = 0$, there is no movement;

- Distance between the point and the loading point [D_{LP}]: Distance given by Equation 3 between points [P_n] and [LP];

- Distance between the point and the crusher point [D_{CP}]: Distance given by Equation 3 between points [P_n] and [CP];

3.4.2.2 Loading Segment [LS_n]

With the data defined previously, the following logic is used to define the Loading Segment [LS_n]:

$$\text{IF } [D_{LP}] < [R] \text{ AND } [M_n] = 0, \text{ THEN } [LS_n] = 1, \text{ ELSE } [LS_n] = 0$$

When [LS_n] = 1, it is a Loading Segment. When [LS_n] = 0, it is not a Loading Segment. Figure 17 schematically represents the proposed logic.

Figure 17 - Loading Segment - schematic representation of the proposed logic.
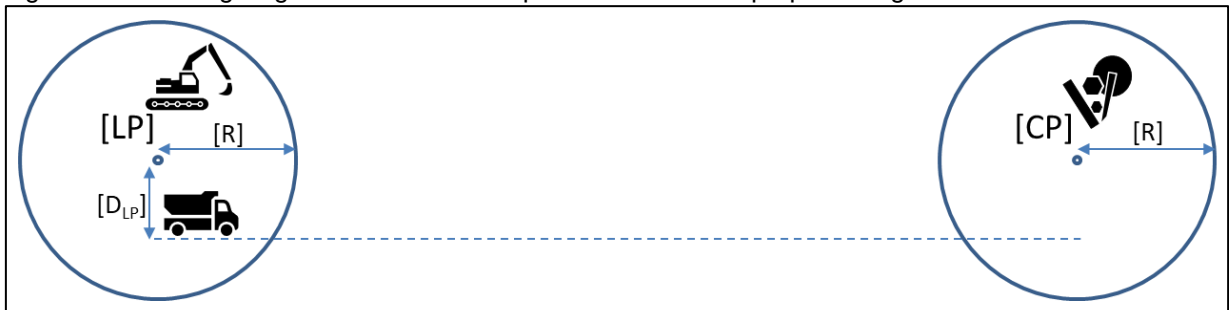
Source: Personal file.

3.4.2.3 Unloading on the Crusher Segment [CS_n]

To classify the segment as Unloading on the Crusher Segment [CS_n] the spreadsheet program should follow the logic:

$$\text{IF } [D_{cp}] < [R] \text{ AND } [M_n] = 0, \text{ THEN } [CS_n] = 1, \text{ ELSE } [CS_n] = 0$$

Figure 18 schematically represents the proposed logic.

Figure 18 - Unloading on the Crusher Segment - schematic representation of the proposed logic.
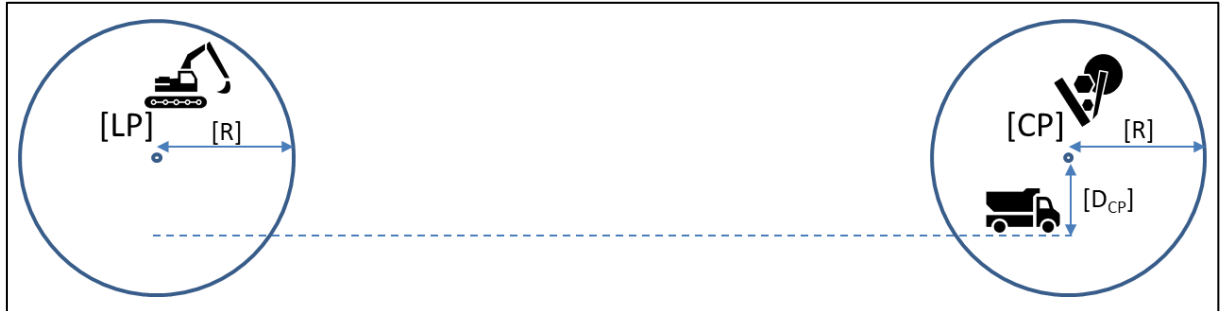
3.4.2.4 Loaded/Unloaded Transport Segment [LTS_n]

To classify the segment as Loaded Transport Segment the spreadsheet program should follow the logic:

IF [LS_n] = 0 AND [CS_n] = 0, THEN [LTS_n] = [LTS_{n-1}],

    IF [LS_n] = 1, THEN [LTS_n] = 1, ELSE [LTS_n] = 0

Where [LTS_n] is a string which will save when the segment is a Loaded Transport Segment. When [LTS_n] = 1, it is a Loaded Transport Segment, when [LTS_n] = 0, it is an Unloaded Transport Segment.

3.4.2.5 Cycle Count [CC_n]

To identify each truck cycle the spreadsheet program should follow the logic:

IF DATE ([T_{n-1}]) = DATE ([T_n]),

    IF [LTS_{n-1}] = [LTS_n], THEN [CC_n] = [CC_{n-1}]

        IF [LTS_n] = 1, THEN [CC_n] = [CC_{n-1}] + 1, ELSE [CC_n] = [CC_{n-1}]

ELSE [CC_n] = 0

3.4.3 Data analysis

With the segments sorted and organized, it is then possible to determine the average times for each activity: loading, loaded transport, unloading, unloaded transport and unproductive times.

In the application example, basically SUMIF and AVERAGEIF functions were used in Microsoft Excel to achieve the results. However, with the data organized one can get the same results regardless of the software or functions.

3.4.3.1 Cycle Time [CT_i]

To sum up each Cycle Time the spreadsheet program should follow the logic.

$$[CT_i] = \sum_{\substack{\text{IF } [CC_n]=i}} [ST_n]$$

That is, [CT_i] is the sum of the Segment Time [ST_n] if the Cycle Count [CC_n] is equal to i.

3.4.3.2 Loading Time [CLT_i]

To sum up each Cycle Loading Time the spreadsheet program should follow the logic.

$$[CLT_i] = \sum_{\substack{\text{IF } ([CC_n]=i \\ \text{AND } [LS_n]=1)}} [ST_n]$$

That is, [CLT_i] is the sum of the Segment Time [ST_n] if the Cycle Count [CC_n] is equal to i AND [LS_n] = 1.

3.4.3.3 Unloading Time [CUT_i]

To sum up each Cycle Unloading Time the spreadsheet program should follow the logic.

$$[CUT_i] = \sum_{\substack{IF\ ([CC_n]=i \\ AND\ [CS_n]=1)}} [ST_n]$$

That is, [CUT_i] is the sum of the Segment Time [ST_n] if the cycle count [CC_n] is equal to i AND [CS_n] = 1.

3.4.3.4 Loaded Transport Time [CLTT_i]

To sum up each Cycle Loaded Transport Time the spreadsheet program should follow the logic.

$$[CLTT_i] = \sum_{\substack{IF\ ([CC_n]=i \\ AND\ [LTS_n]=1 \\ AND\ [M]=1)}} [ST_n]$$

That is, [CLTT_i] is the sum of the Segment Time [LT_n] if the Cycle Count [CC_n] is equal to i AND [LTS_n]=1 AND [M_n]=1.

3.4.3.5 Unloaded Transport Time [CUTT_i]

To sum up each Cycle Unloaded Transport Time the spreadsheet program should follow the logic.

$$[CUTT_i] = \sum_{\substack{IF\ ([CC_n]=i \\ AND\ [LTS_n]=0 \\ AND\ [M]=1)}} [ST_n]$$

That is, [CUTTi] is the sum of the Segment Time [STn] if the Cycle Count [CCn] is equal to i AND [LTSn]=0 AND [Mn]=1.

3.4.3.6 Unproductive Time [CUPTi]

The time that the truck is not loading, unloading or transporting, is an Unproductive Time of the cycle which can be defined as follow (Equation 6).

$$[CUPT_i] = [CTi] - ([CLTi] + [CUTi] + [CLTTi] + [CUTTi])$$

Equation 6

3.4.3.7 Average times

With all the information organized and classified the average times of each operation can be calculated using an AVERAGE function of the spreadsheet software.

3.4.3.8 Cycle classification

To avoid using collected data that could disrupt the analysis, another string was created. This variable compares the cycle time with the average of the cycle times collected, recording the number 1 for cycles that should be considered and 0 for cycles that should not be considered.

Thus, the analysis will not consider extremely short cycles, which may have been due to some data collection error, or extremely long cycles, which may have been caused due to lunch stops or equipment breaks. The first and last cycle of the day are also discarded because they are the cycles in which the truck is going or coming from the garage or diesel filling station.

3.4.3.9 Diesel consumption

The consumption of diesel in liters per hour (l/h) was calculated by dividing the liters of fuel that were supplied to the equipment by the number of hours worked.

4 RESULTS

In order to validate the proposed logic, the system was tested in the application example. The following is a description of the test performed and the results obtained.

4.1 DATA COLLECT

The data used in this work were collected during the period between January and February 2018. It was used 1 GPS sensor installed in 1 truck, the data was manually downloaded at the end of the day and inserted into a Microsoft Excel worksheet pre-programmed with the proposed logic.

As the truck is always fueled with diesel at the end of the work shift, it always starts the day with the full tank. Thus, the volume of diesel supplied is the volume of diesel that was consumed for operation during that day. This consumption data was recorded manually.

4.2 DATA PROCESSING

The track file generated by the GPS sensor has proved true to reality, as shown in Figure 19. The Loading Point [LP] was updated according to the mining advance and the Crusher Point [CP] was set. It was adopted a Proximity Radius [R] of 30 m and a Speed Tolerance [V_{tol}] of 5 km/h.

Figure 19 – Tracks collected in the application example.

Source: Personal file (Track data: January/February 2018. Image: Google Earth – Digital Globe 2019, Satellite image taken in November 2017).

4.3 DATA ANALYSIS

From the data processed it was possible to obtain the times of each phase of the loading and transport cycle. It is important to note that 85% of the cycles were considered according to the logic of the Cycle Classification.

Figure 20 shows the boxplot graph of the average times considering the data collected in the application example.

Figure 20 – Boxplot graph of the average times.
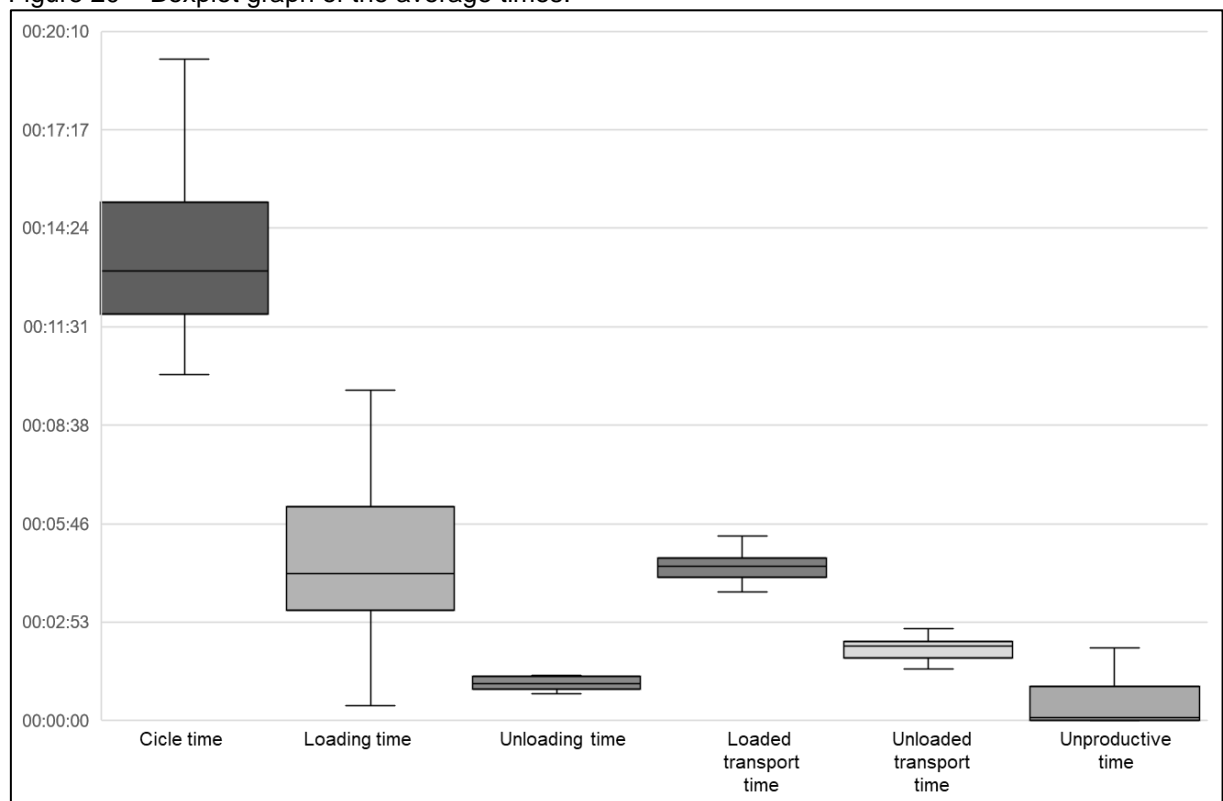
Source: Personal file.

The analysis of the presented boxplot shows that the activities of unloading on the crusher, loaded transport and unloaded transport present small variations in relation to the average when compared to the loading time.

Field observation showed that loading activity indeed varies greatly in time, as the hydraulic excavator at the time of measurement was undersized to truck capacity. Thus, it was necessary to repeat the bucket unloading movement in the truck and pile preparation too many times.

Another point to note is unproductive time, which presents a wide variation as well. This can be justified since events that generate unproductive periods are neither constant nor frequent.

Figure 21 shows the graph with the evolution of the number of truck cycles that were measured during the test period.

Figure 21 – Evolution of the number of truck cycles during the test period.
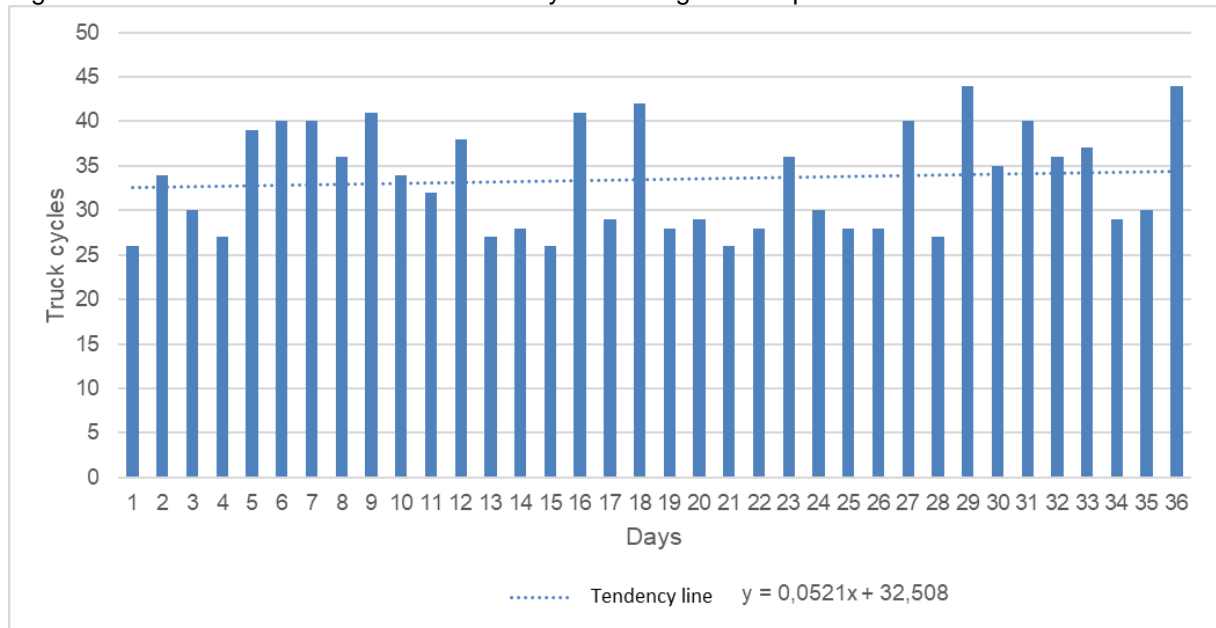
Source: Personal file.

The graph shows that the trend line revealed an increase in the number of cycles of about 5%. This increase can be justified once the activity has been monitored, the workers feel observed and tempted to present good results.

In the application example the historical consumption of the trucks was around 30 l/h. During the period of application of the tool the average consumption of diesel presented an average of 27.8 l/h, a drop of 7% in consumption.

The consistency of these results shows that it is possible to obtain data with the resources presented.

4.4 TEST COSTS

The table shows the costs for performing the test in the application example.

Table 7 – Tests costs.

ITEM	DESCRIPTION	QTY	UNIT COST (USD)	TOTAL COST (USD)
1	Garmin etrex 30X Portable GPS	1	370.00	370.00
2	Office 365 - Annual subscription	1	110.00	110.00
	TOTAL			**480.00**

Source: Personal file.

There are freeware options such as FreeOffice or LibreOffice, as well as cheaper options for GPS sensors, which can help lower the investment in such a system at other companies.

5 DISCUSSION

In addition to obtaining the data in the application example presented in the previous chapter, this paper aims to demonstrate if it is possible to monitor the production of the ore transport with a low-cost system.

Through a GPS sensor, spreadsheet software and simple logic programming it was possible to have a tool that measures the times of the main activities of the loading and hauling process. Considering the material used in the application example test, this tool would cost approximately US$ 480. If GPS sensors were installed on all four quarry trucks, the solution would cost US$ 1,590, as shown in Table 8.

Table 8 – Estimated cost for installation in all trucks of the Quarry.

ITEM	DESCRIPTION	QTY	UNIT COST (USD)	TOTAL COST (USD)
1	Garmin etrex 30X Portable GPS	4	370.00	1,480.00
2	Office 365 - Annual subscription	1	110.00	110.00
	TOTAL			1,590.00

Source: Personal file.

Considering the application example, each truck cycle carries about 25 t of ROM, 20 t being salable material[4]. If the average sale value is 10 US$/t, each truck cycle generates a revenue of US$ 200. Considering also a margin of 5% profit, each truck cycle would generate a profit of US$ 10.

Considering the cost of US$ 1,590, 159 truck cycles would pay all the investment. In a quarry that produces 600,000 t per year of ROM, corresponding to 24,000 truck cycles, a slight increase in production of 1% would already be more than enough to make the system viable.

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[4] It is estimated that 20% of the ROM is made up of a Crusher run, fine material without quality for concrete mixing. This material is mainly used on asphalt base, and there is only sporadic demand for this product in the region of the application example.

As shown in the Results chapter, during the test an increase in the number of cycles of 5% was noticed. More than enough to pay the investment and present good financial results.

As demonstrated, ore transport monitoring has not only brought economic benefits, but also brought environmental benefits with the reduction of diesel consumption. Considering the number of annual cycles and the average cycle time, an annual saving of about 12,600 liters of diesel can be achieved in an operation the size of the application example.

According to U.S. Environmental Protection Agency (2005), the burning of diesel generates 22.2 pounds of CO_2 per gallon of diesel, or 2.7 kg CO_2 per liter of diesel. So, it would be prevented the release of about 33 tons of CO_2 per year in this operation.

6 CONCLUSIONS

According to the research carried out in this dissertation, it is possible to affirm that small and medium-sized companies play a very important role in the economy. Although it is known that the use of new technologies brings benefits, these companies present difficulties in their implementation due to cultural, social and economic reasons.

Likewise, small and medium-sized mining companies are very numerous and important, but also have difficulties in implementing new technologies. Research has shown that this difficulty is not unique to the mining industry, as it is a great user of new technologies and has the same level of innovation as other industries.

The mining industry is still largely responsible for the development of humanity, and its operations require large amounts of resources, such as diesel and tires in ore transport operations. This operation alone is responsible for more than half of the mining operation cost and most of the emission of greenhouse gases in this kind of operation.

According to the data presented in this document one can confirm that yes, it is possible to monitor the production of ore hauling in a small mining enterprise with a low-cost system. Not only that, it is also possible with the implementation of the tool to witness an increase in the production of the activity and consequently a better use of natural resources (minerals and fossil fuels).

A more elaborate sensor and programming could have been used. However, it is not the purpose of this work to explore to the exhaustion the means to arrive at the final result, but rather to prove that with limited resources it is possible to reach relevant results.

The next steps of the research will be the determination of the technologies that could be used to obtain the results in order to eliminate the processing of the data in worksheets and to automate the analysis and generation of indicators through cloud systems, focusing on small and medium mines and the low implementation and maintenance costs.

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