# LEAN TOOLS SELECTION FOR MINING: AN OCCUPATIONAL HEALTH AND SAFETY APPROACH

by

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**Sélection des outils lean pour l'exploitation minière : une approche basée sur la santé et sécurité au travail**

Ali NEMATI ROUZBAHANI

## RÉSUMÉ

La mise en œuvre des principes Lean est un sujet bien connu dans les industries manufacturières. Il existe de nombreuses publications concernant l'impact de cette mise en œuvre sur la productivité et la santé et la sécurité des travailleurs (SST) dans ce secteur. Dans les industries minières, toutefois, le lien entre l'intégration des principes Lean et la SST est manquant et les publications sur ce sujet sont rares.

Dans ce mémoire, nous avons tenté de résoudre ce problème et d'étudier davantage l'utilisation des principes Lean en extraction minière au Canada. À cette fin, une revue de la littérature suivie d'une étude auprès d'experts a été réalisée. Les principaux objectifs de ce mémoire étaient de rechercher les outils Lean adéquats à mettre en œuvre dans l'industrie minière et d'étudier leurs liens avec le principal indicateur de productivité utilisé (taux d'avancement journalier) et les indicateurs de SST prépondérants (réaction du corps et frappé par un objet) dans l'exploitation souterraine Canadienne de l'or.

À la lumière des résultats de cette thèse, il a été suggéré d'utiliser un cadre de cycle de vie d'une mine Lean avec quatre phases différentes et un ensemble d'outils Lean (VSM, 5S, Kaïzen, TPM, SMED et LIC) pour le secteur minier. De plus, selon l'élicitation auprès de sept experts canadiens, 5S et TPM pourraient avoir un impact positif sur le taux d'avancement journalier et Kaïzen pourrait potentiellement améliorer la santé et la sécurité des mineurs en réduisant le risque d'être frappé par un objet sur leur lieu de travail. Finalement, une feuille de route préliminaire pour l'exploitation minière Lean a été proposée sur la base de ces résultats.

Les résultats de ce mémoire sont un premier pas vers de futures études visant à mieux comprendre l'utilisation des principes Lean intégrés aux considérations de santé et de sécurité du travail dans le secteur minier canadien.

**Mots-clés**: exploitation minière Lean, outils Lean, la santé et la sécurité au travail, élicitation d'experts, mine souterraine Canadienne de l'or.

**Lean Tools Selection for Mining: An Occupational Health and Safety Approach**

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## ABSTRACT

The implementation of lean principles is a well-known subject in the manufacturing industries. There are several publications regarding the impact of this implementation on productivity and workers' occupational health and safety (OHS) in this sector. In mining industries, however, the link between lean integration and OHS is missing and the publications regarding this issue are scarce.

In this thesis, an attempt was made to address this issue and investigate more about lean mining in Canada. For that purpose, a literature review followed by an expert elicitation study were conducted. The main objectives of this thesis were to find out about the proper lean tools to be implemented in the mining industry and to investigate about their links with an important productivity indicator (i.e. daily advance rate) and OHS indicators (i.e. body reaction and struck by an object) in the Canadian underground gold mining.

Based on the results of this thesis, a lean mining lifecycle framework with four different phases and a set of lean tools (i.e. VSM, 5S, Kaïzen, TPM, SMED and LIC) were proposed for the mining sector. Furthermore, according to the expert elicitation (7 Canadian experts), 5S and TPM could have positive impacts on daily advance rate and kaïzen could potentially enhance the miners' safety by reducing the rate of struck by an object risks at their workplace. A lean mining preliminary road-map was proposed based on these findings.

This study's results can be used as a stepping stone in future studies to gain a better understanding about lean mining integrating OHS issues in Canada.

**Keywords**: lean mining, lean tools, occupational health and safety, expert elicitation, Canadian underground gold mining.

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| | |
|---|---|
| AQHSST | Association Québécoise pour l'Hygiène, la Santé et la Sécurité du Travail |
| CNESST | Commission des Normes, de l'Équité, de la Santé et de la Sécurité du Travail |
| EFQM | European Foundation of Quality Management |
| ÉTS | École de technologie supérieure |
| IRSST | Institut de recherche Robert-Sauvé en santé et en Sécurité du Travail |
| JIT | Just-in-time |
| LIC | Lean Information Center |
| LM | Lean Manufacturing |
| LT | Lean Tools |
| MERN | Ministère de l'Énergie et des Ressources Naturelles |
| MQW | Mahindra Quality Way |
| MSD | MusculoSkeletal Disorders |
| MSI | MusculoSkeletal Injuries |
| OHS | Occupational health and safety |
| PAP | Production Assurance Program |
| SLT | Selected Lean Tools |
| SMED | Single-Minute Exchange of Dies |
| TPM | Total Productive Maintenance |
| UQAT | Université du Québec en Abitibi-Témiscamingue |
| VSM | Value Stream Mapping |

# INTRODUCTION

Lean thinking or lean production (first introduced in the manufacturing sector and originated from Toyota Motor Company in Japan) is an application of the Just-in-Time (JIT) philosophy. JIT philosophy has two main pillars. One is based on the total wastage removal through accurate planning of the production, i.e. how and when to deliver the required resources for the production. The other one focuses on human factors (e.g. dignity and respect) and includes them into the production procedure (Nadeau, Morency, & Nsangou, 2015). Ohno stated the main purpose of JIT as: *"Making a factory operate for the company just like the human body operates for an individual"* (Ohno, 1988, p. xi). Consequently, the industrial implementation of lean must not deteriorate workers occupational health and safety (OHS) conditions (Nadeau, S. et al., 2015). Proper implementation of JIT can enhance the quality and reduce the waste (Cheng & Podolsky, 1996).

In lean production, the value is described as any kind of process, product or service that a customer might be interested to acquire. Accordingly, the major idea in lean production is to keep the customer value at its maximum level by minimizing all types of waste (Womack & Jones, 2010). In that regard, improving the waste management system will help the companies to eliminate different type of wastes efficiently (Yingling, Detty & Sottile, 2000). An important goal of applying lean principles by an organization is to deliver the best values to the customers. This can be accomplished by creating an optimized procedure for value production without wastes. To achieve this goal, the management team must concentrate on optimizing the product or service flow of the whole company. The application of lean inside companies should be applied in a holistic approach. Merely focusing on individual departments for applying lean may not be helpful (Womack & Jones, 2010). Fig 1.1 shows the proposed steps for the implementation of lean principles in an organization.

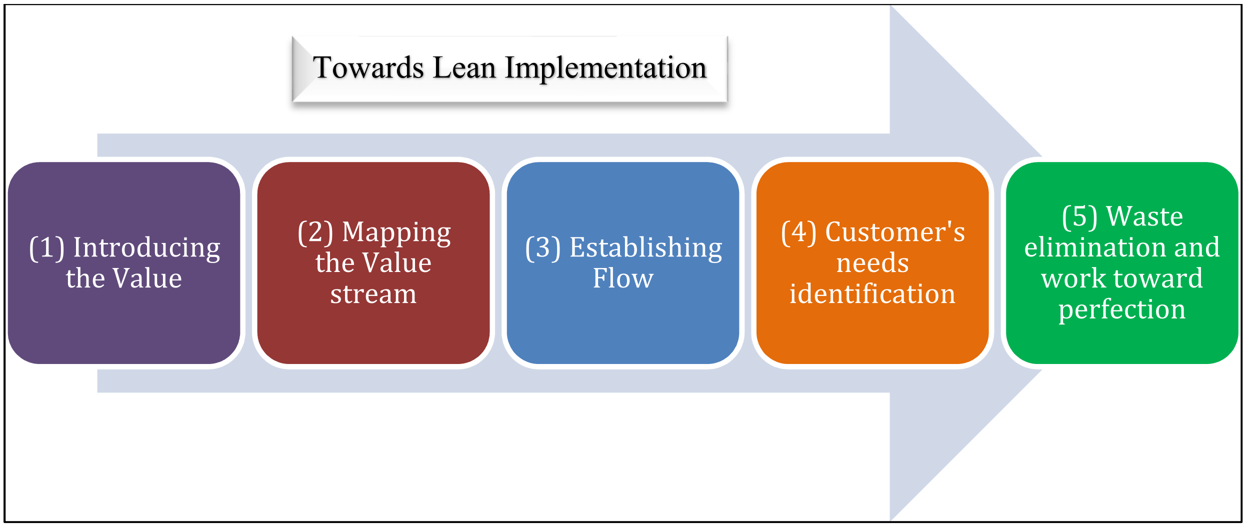


Figure 0.1 Lean implementation in organizational procedures adapted from Womack et al. (2010)

After witnessing the successful experience of implementing lean in the manufacturing industries, other sectors start to use this type of production management in their daily activities. Sectors such as healthcare (D'Andreamatteo, Ianni, Lega & Sargiacomo, 2015), public service (Gupta, Sharma & Sunder, 2016), electronic devices assembly line (Zakaria et al., 2017), and universities (Balzer, Brodke & Thomas Kizhakethalackal, 2015) are few examples of organizations other than manufacturing, that are trying to implement lean thinking. It's worth mentioning that unlike the manufacturing sector, there are little information and studies about the outcome of lean implementation in the other sectors (Hasle, 2014). One of the sectors that has very little or no published information about implementing lean is the mining industries (Hattingh & Keys, 2010). Different nature of the mining environment compared to the manufacturing sector and uncertainty are two key reasons for this lack of information (Flynn & Vlok, 2015). In this thesis, an attempt is made to investigate about implementing lean into mining industries.

In the first chapter of this thesis, relative literature to applied methods and tools for implementing lean in the manufacturing and mining industries are reviewed. The main aim of the first chapter is to point out the existing barriers and challenges in the way of implementing lean into the mining industries (lean mining) and formulating the research question and the objective of this thesis. Consequently, two objectives are defined based on the research question (see section 1.7).

The research methodology of this thesis is discussed in Chapter 2. Defining the approach and the required tools for addressing the two objectives of this thesis and answering the research question are the main goals of this chapter.

The first objective (see section 1.7) is addressed in a conference paper submitted to CIGI QUALITA conference (Nemati, Nadeau, Ateme-Nguema & Belmonte, 2019). This conference paper is available in Appendix II.

The second objective (see section 1.7) is addressed in a journal paper submitted to the journal of Safety and Health at Work (Nemati, Nadeau & Ateme-Nguema, 2019). This journal paper is available in Chapter 3 of this thesis.

A list of the publications resulting from this thesis is available in Appendix I.

A vulgarization poster presentation was also done at the AQHSST's annual conference based on the findings in the literature review section. This poster is presented in the Appendix III.

# CHAPTER 1

# THESIS RESEARCH QUESTION

This chapter presents the research question and puts it into perspective of this thesis. The main aim is to formulate the research problem comprehensively and accurately. The major tools for the integration of lean are listed in section 1.1. A brief description about the most cited tools in the consulted literature is provided as well. In section 1.2, recent studies about applying these tools in manufacturing sectors are reviewed. The impacts of the application of Lean Tools (LT) on OHS in manufacturing industries are presented in section 1.3. Lean integration in the mining sector and its related barriers and challenges are discussed in section 1.4. The impacts of LT implementation on OHS in mining industry are presented in section 1.5. Subsequently, in section 1.6, the research question and in section 1.7, the research objectives are eventually formulated.

All of the papers and technical reports about lean production systems were obtained through searching these scientific databases: Compendex and INSPEC, IEEE Xplore, Espace ÉTS, Scopus, ProQuest, ScienceDirect, and Google Scholar. Different combinations of keywords and searching methods were used, including: “Lean”, “OHS”, “Lean manufacturing”, “Lean tools”, “Toyota”, “Implementation”, “Mining” “Underground mining”, “Just in time”, “JIT”, “VSM”, “5S”, “Kaïzen ”, “SMED”, “TPM”, “Kanban”, “Health”, “Human factors”, “Safety” and “Ergonomics”. The search operation was also enhanced by applying combinations of the keywords using AND/OR/NOT operators. Both peer reviewed papers and conference documents were considered in the critical literature reviewing section. Only those documents which were published in English language were taken into consideration. Apart from few key resources, most of the cited papers were published within the last 6 years. Finally, the titles and abstracts of the initial documents were reviewed to identify the most relevant materials to the anticipated literature review.

## 1.1 Lean tools

There are varieties of descriptions about the lean production concept in the literature (Womack & Jones, 1994; Rothstein, 2004; Seth & Gupta, 2005; Shah & Ward, 2007, Alves, Dinis-Carvalho & Sousa, 2012). Therefore, it is very hard to find a generally accepted definition about lean production (Hasle, 2014). According to a literature review by Pettersen (2009), a general agreement between authors about parameters and factors associated with lean does not exist. Bhamu & Sangwan (2014) performed a literature review study within 209 published research papers about different definitions of lean production. Among these papers, they found over 33 definitions for lean production. For instance, Womack & Jones (1994), defined lean production as *an integrated model that uses a set of tools and strategies for enhancing the whole production system*. Satoglu, Ustundag, Cevikcan & Durmusoglu (1999), presented lean production as *an effective way to meet the customer needs while remaining competitive with other producers*. Among these definitions about lean production, perhaps one of the most cited among authors was presented by Shah & Ward (2007), which could grasp the major characteristics of lean production (i.e. wastage removal and good human factors): *"An integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability"* (Shah & Ward, 2007, p.791). Eventually, this definition of lean is used in this paper.

Some authors commented about the way that companies are implementing lean tools (Radnor, Holweg & Waring, 2012; Ståhl, Gustavsson, Karlsson, Johansson & Ekberg, 2015). They argued that these tools are mainly used for elimination of every activity that lead to creating waste without considering the actual concept of lean (Randor et al., 2012; Ståhl et al., 2015). Failure to combine social aspects with lean production can lead to limited positive results (Mazzocato, Savage, Brommels, Aronsson & Thor, 2010; Ståhl et al., 2015). On the other hand, considering the social aspects (e.g. human respect, recognition, and involvement in decision-making process) may have positive impacts on the workplace (Ståhl et al., 2015).

According to Sternberg et al., (2012), there are seven categories of wastes that a lean production system focuses to eliminate or reduce: over/underproduction, idle or waiting time, over-processing, excessive transportation of materials, unnecessary movement, extra inventory accumulation and defects/overquality in production. Number of tools have been introduced over time to eliminate these wastes (Bhamu & Sangwan, 2014). It is worth mentioning that there could be multiple names for LM tools and some of them might overlap with one another. In addition to that, different ways and strategies were proposed by researchers for implementation of each tool (Pavnaskar, Gershenson & Jambekar, 2003). Based on the performed literature review by Bhamu & Sangwan (2014) and Hodge, Goforth Ross, Joines & Thoney (2011), the most important tools for implementation lean production in manufacturing (LM) can be categorized as below:

### 1.1.1 Five S

The five S (5S) is about setting up standards for cleaning and housekeeping the industrial workplace. It includes the initials of five Japanese words. After translation to English, these words would be (Flynn et al., 2015):

- Sorting: to rearrange the workplace to make it empty of unnecessary belongings
- Stabilizing : to arrange the equipment and belongings in the work environment
- Sweeping : to fully clean the work environment
- Standardizing: to constantly keep the cleanliness of the workplace
- Sustaining the practice: to try to continue the whole procedure in the future

### 1.1.2 Value stream mapping

The value stream mapping (VSM) is a tool for analyzing and enhancing the necessary information or materials' flow that are required for delivering the value to the customers. By using VSM, identification of waste occurrence in the production system will become easier (refer to table 1.1 for more examples). VSM is useful for identifying the following factors. These factors can effectively contribute to waste elimination (Venkataraman et al., 2014):

- Value added time: The amount of spent time for adding value to the final product and its production.

- Non-value added time: The amount of spent time which does not result in final production.
- Cycle time: The amount of required time for performing one cycle in a process.
- Changeover time: The amount of required time for replacing tools in a process.

### 1.1.3 Kaïzen

Kaïzen is a Japanese word meaning '*continuous improvement'*. It is used for simplifying the workplace. It focuses on creating small but frequent improvements to the process. In Kaïzen, everyone in the lean implementation team could be involved in making small enhancements into their workplace. Overtime, remarkable outcomes can be seen by small changes that have been gradually accumulated (Maurer, 2014).

### 1.1.4 Single-Minute Exchange of Die

The single-minute exchange of die (SMED) is an important tool for waste management in a manufacturing process. It decreases the setup time while performing a changeover action (Carrizo Moreira et al., 2011). SMED offers a continuous solution for reducing the waiting and idle time between manufacturing the current and the next product (Antunes et al., 2016). SMED`s main goal is to decrease a machine`s setup time. Setup time can be regrouped in two families: external and internal setup. External setup includes those activities that can be performed when machines are still running. Internal setup is limited to those activities which can be done only when machines are shut down. One of the SMED`s basic feature is to perform as much as possible activities between internal and external setup (Dave et al., 2012).

### 1.1.5 Total Productive Maintenance

The total productive maintenance (TPM) is a maintaining tool that focuses on enhancing the quality system and the manufacturing integrity of equipment in a company. TPM keeps the entire equipment in their best working conditions. It also ensures that breakdowns and delays due to equipment’s malfunction can be avoided. There are five main pillars for TPM (Mishra et al., 2016):

1- Enhancing effectiveness of equipment;
2- Enhancing effectiveness and efficiency during maintenance;
3- Avoiding early equipment maintenance;
4- Improving involved workers` skills;
5- Increasing operators’ involvement in the maintenance process.

### 1.1.6 Kanban

Kanban is a tool with a systematic approach to achieve proper controlling over the supply chain. It was designed to gain control over the level of inventory and the production elements while implementing LM in an organization (Sundar, R. et al., 2014). Kanban is a Japanese word, firstly introduced by Toyota, meaning ‘*signal card*’. It can be categorized as a two cards system for giving signal to both production line and inventory to keep the production flow and inventory size at optimum conditions (Sundar, R. et al., 2014). Kanban’s goal is to set an upper limit to the production rate and to avoid overloading during the manufacturing time. It is a multi-level inventory management system and can be used for controlling the production rate (Rahman et al., 2013).

## 1.2 Lean tools and their economic impacts in manufacturing industries

The main purpose of this section is to find the links between the selected lean tools (LT) and their impacts on economic conditions of industries in general (manufacturing sector). According to the literature, there are several organizations in the manufacturing sector, which gained positive economical results after integration of LT throughout their activities (Flynn et al., 2015; Bhamu et al., 2014). Some companies in this sector (automotive, computer, electronic industries, and so on) have been in the front line of LT implementation compared to other companies (Flynn et al., 2015). Other industries such as textile manufacturing have attempted to implement lean as well (Dharun Lingam et al., 2015). A number of literature reviewing publications exists regarding the different experiences of lean implementation into manufacturing industries (Hasle, 2014; Bhamu et al., 2014).

Regarding the economic aspect of LM, the following results were reported in the literature for each selected LT presented in the section 1.1:

Production rate increase in a clothing company (Ramdass, 2015), cycle time reduction in a plant packaging line (Srinivasan et al., 2016), costs and expenditures reduction in a textile company (Ramdass, 2015) and workplace overall space reduction in a switchboard company (Acharyaa, 2011) were reported after implementation of 5S. Productivity enhancement in an assembly line and a processing company (Kuhlang, Edtmayr & Sihn, 2011; Sabaghi et al., 2014), system performance improvement in a glass fabrication plant (Atieh, Kaylani, Almuhtady & Al-Tamimi, 2016) and reduction in production cycle time in a flexible pipe industry (Božičković et al., 2012) were obtained after integration of VSM. Implementation of Kaïzen in conjunction with other tools such as VSM, 5S and SMED resulted in production time reduction in a textile manufacturing company (Dharun Lingam, Sakthi & Kumar, 2015), increase of production capacity in a shoe company (Chowdhury, Shahriar, Hossen & Mahmud, 2017) and productivity improvement in an air conditioning coil production line (Das, Venkatadri & Pandey , 2014). Setup time and changeover time reduction in automotive factories (Deros et al., 2013; Kumar & Abuthakeer, 2012), industrial valve plant (Ashif, Goyal & Shastri, 2015) and a furniture company (Suhardi, Sahadewo & Laksono, 2015) were reported after using SMED. TPM integration resulted in maintenance time reduction in a furniture production plant (Bednarek, M., 2013) and equipment effective processing time enhancement in an automotive company (Bednarek, 2013). Finally, implementation of Kanban and VSM resulted in more efficient workplace organization in an industrial color manufacturing company (Rohani & Zahraee, 2015) and production line material flow improvement in a plant`s assembly line (Álvarez, Calvo, Peña & Domingo, 2009). Table 1.1 summarizes the result of recent case studies about implementing LT in manufacturing industries. These studies mainly reported positive economical results of LT integration.

Kumar & Abuthakeer (2012) studied the possibility of applying SMED for decreasing the final production time in an automotive company. In their study, they used the statistical data collection method to reveal the most time consuming steps in this manufacturing process, so the amount of time lost in different shifts could be measured. They summed up that using SMED enabled the company to reduce the changeover time around 6% in one working day (without a significant increase in the workload). Although they claimed that enhancement in the OHS conditions and improvement in workers` motivation were obtained after implementation of SMED; however, no valid data and statistical method were presented to support that statement. Therefore, drawing a conclusion about successful integration of lean regarding its socio-technical aspect in this company may not be possible. Moreover, adaptability of other lean tools such as Kaïzen and 5S in this workplace has not been studied.

Ashif et al. (2015) followed the same approach to integrate SMED and VSM into a valve manufacturing company in India. Their main goal was to reduce the setup time and the lead-time. According to their results, by separating the actions that do not yield in extra value to the final product, usage of SMED tool decreased the setup time up to 24% per each action. Moreover, VSM could successfully reduce the lead-time around 8%. The OHS aspect of lean is still missing from this study and again positive results are limited to technical aspects (i.e. process lead time and setup time reduction). In this case, the influence of lean implementation on social factors either has not been studied or documented. Božičković et al. (2012) worked on the possibility of obtaining higher efficiency and productivity using VSM in a flexible pipe manufacturing industry in Bosnia. They recognized that VSM could be effective in synchronization of the process while the production is on line. One of the highlights of this study was to discover that lean implementation was applicable without any changes in the number of employees. The employees were initially reluctant to accept new changes in their workplace mainly because they were afraid about the possibility of job loss. Other related reasons for this unwillingness had not been investigated so far. Furthermore, no measurement was taken to show the workers’ level of contribution and change of behavior after implementation of lean. Dhaurun Lingam et al. (2015) investigated VSM and Kaïzen integration in a traditional textile industry in India. Their main aim was to reduce the production lifecycle. They mentioned that in the process industries such as textile, implementation of lean production could become a challenge due to usage of machines that are highly flexible and their final products have high variety. However, they didn`t exactly specify what is the challenge for lean implementation. Firstly, the improvement in the process lifecycle was performed using Kaïzen after recognizing the non-value added activities. In the next step, VSM was used to measure the amount of reduced times in overall activities for producing the final product. The results revealed that implementation of lean by utilizing Kaïzen and VSM in this industry could reduce the production lead-time around 20%. This study is limited to usage of VSM and Kaïzen for identifying and eliminating workers and machines' idle time. No further investigation has been made to specify the social and OHS aspect of using these lean tools on the workers. Consequently, complete outcome of lean integration cannot be seen from this case study.

### 1.3 Lean tools and their impacts on OHS in manufacturing industries

In this section, a literature review about social aspect of LM will be conducted. The main objective of this section is to find the links between the selected LT and OHS in the manufacturing industries. According to the literature, apart from the positive results in integrating the technical aspect of LM, there are certain drawbacks and limitations for LT integration considering the OHS aspect. Some studies showed that LM could have negative influences on the employees' overall health and safety, known as OHS issues. To some extent, the researchers claim that lean is not very friendly with the workers (Brännmark & Håkansson, 2012; Adler, 1999). It can add up to the intensity and the workloads of the employees (Westgaard & Winkel, 2011). Besides, it can increase the accidents and injuries rate and deteriorate the level of health and increase stress among workers (De Treville & Antonakis, 2006; Brenner, Fairris & Ruser, 2004). Lean, by reducing the cycle time of manufacturing activities, could increase the workload, repetitiveness, and workers effort (Brännmark & Håkansson, 2012).

Table 1.1 Review of recent case studies regarding LT implementation in the manufacturing sector

| *Row* | *Author(s)* | *Industry* | *Country* | *Tools* | *Effects on Economical aspect of LM* |
|---|---|---|---|---|---|
| 1 | Chowdhury et al. (2017) | Shoe company | India | VSM, 5S, Kanban, Kaïzen | 8% reduction in overall lead time, 8.8% capacity increment |
| 2 | Srinivasan et al. (2016) | Packaging line in a plant | USA | 5S | 16.6% reduction in the cycle time for assembling process |
| 3 | Atieh et al. (2016) | Glass fabrication | Jordan | VSM | Improvement in system performance |
| 4 | Rohani & Zahraee (2015) | Color | Malaysia | VSM, 5S, Kanban | Efficient workplace organization, remove waste due to machines' failures |
| 5 | Ramdass (2015) | Textile | South Africa | 5S | 80% reduction in waste in costs over 3 years |
| 6 | Ramdass (2015) | Clothing | South Africa | 5S | 30% increment in final production rate |
| 7 | Dharun Lingam et al (2015) | Textile | India | VSM & Kaïzen | 20% reduction in production time |
| 8 | Ashif et al. (2015) | Valve manufacturing | India | VSM & SMED | 8% reduction in lead time, 24% reduction in setup time |
| 9 | Suhardi et al. (2015) | Furniture | Indonesia | VSM, SMED | 53% reduction in setup time |
| 10 | Sabaghi, Rostamzadeh & Mascle (2014) | Processing company | Iran | VSM, TPM, SMED, Kanban | Productivity improvement |
| 11 | Das (2014) | Air conditioner coil manufacturer | India | VSM, SMED, Kaïzen | 77% improvement in productivity, 67% reduction in setup time |

Table 1.1 Review of recent case studies regarding LT implementation in the manufacturing sector (Continued)

| *Row* | *Author(s)* | *Industry* | *Country* | *Tools* | *Effects on Economical aspect of LM* |
|---|---|---|---|---|---|
| 12 | Guan & Liao (2014) | Bellows manufacturing company | India | 5S | Enhancement in production system |
| 13 | Rose, Deros & Rahman (2013) | Automotive | Malaysia | SMED | Over 35% decrease in setup time |
| 14 | Valle et al. (2013) | Automotive | Brazil | VSM & SMED | 75% reduction in overall changeover time |
| 15 | Bednarek (2013) | Automotive | Singapore | SMED & TPM | 36% decrease in changeover time, equipment effective processing time were enhanced by 15% |
| 16 | Bednarek (2013) | Furniture | Singapore | TPM | Over 72% reduction in maintenance time |
| 17 | Kumar & Abuthakeer (2012) | Automotive | India | SMED | 6% reduction in changeover time |
| 18 | Božičković et al. (2012) | Flexible pipe industry | Bosnia and Herzegovina | SMED & VSM | 20% reduction in production cycle time |
| 19 | Kuhlang et al. (2011) | Assembly line in a plant | Austria | VSM | Productivity improvement |
| 20 | Acharyaa (2011) | Switchboard company | India | 5S | 30% saving of overall spaces in the workplace |
| 21 | Álvarez et al. (2009) | Assembly line in a plant | Spain | VSM & Kanban | Improvement in material flow in the production line |

On the other hand, number of studies pointed out that negative effects of lean might be because of improper integration, not sufficient experience, and lack of commitment in the management level while using LT (Ferreira, Baptista, Azevedo & Charrua-Santos, 2015; Dal Forno, Pereira, Forcellini & Kipper 2014). Longoni, Pagell, Johnston & Veltri (2013) carried out a literature reviewing study about some major lean impacts on OHS. They undertook 10 different case studies including variety of industries with different sizes and population all located in Canada. In their research, they defined proper implementation of lean as simultaneously combining the technical aspects of LM with the OHS aspects. Using a qualitative method, they designed an exploratory research for evaluating rate of injuries in their case studies. According to the findings, they concluded that proper implementation of lean could create a better working environment for the workers for continuous waste elimination. Recent cases studies about implementing LT in manufacturing sector only considered and evaluated the technical aspect of LM without including the impact of this integration on OHS (e.g. Atieh et al., 2016; Sabaghi et al., 2014; Bednarek, 2013). Few of these studies pointed out that using LT could lead to an enhancement in workers' safety and working conditions. However, they did not investigate it any further (e.g. Chowdhury et al., 2017; Ramdass, 2015). For instance, when Chowdhury et al (2017) studied the implementation of 5S in a shoe factory, they proposed that changing some equipment such as chairs and cutting scissors in the assembly line can reduce workers' fatigue by a better ergonomic design. However, they did not conduct further examinations to support their statement about reducing fatigue.

Regarding the OHS aspect while implementing LM, some authors mentioned that using VSM could intensify working conditions by increasing the working hours (Jarebrant et al., 2016; Westgaard & Winkel, 2011). This might cause development of musculoskeletal disorders (MSD) among the workers by intensifying the daily workload (Jarebrant et al., 2016). In another study, an increase in the rate of MSD issues after implementation of continuous improvement (Kaïzen) activities was reported by Sakouhi & Nadeau (2016). They mentioned that changes in organizational behaviour due to unsustainable implementation of lean could be a reason for this raise in the rate of MSD among workers. They also mentioned that as sustainability in lean integration increases, the OHS conditions could potentially improve. On the other hand, Rohani et al (2015) reported an enhancement in workplace safety and quality in a color manufacturing company after integration of VSM, 5S and Kanban. Improvements in the safety of the workplace were observed after implementation of 5S by few industries (Srinivasan et al., 2016; Filip & Marascu-Klein, 2015). TPM can provide a clean work environment and a constant maintaining plan for replacing old machines with new ones to decrease breakdowns which can contribute to reduce the injury rate between workers (Longoni, Pagell, Johnston & Veltri, 2013). In addition to that, TPM provides more space in the workplace for workers to move. It can reduce the possibility of colliding with objects in the workplace which may lead to injuries (Finnsgård, Wänström, Medbo & Neumann, 2011). Longoni et al. (2013) mentioned that proper implementation of TPM in an industry requires high levels of workers skills and awareness. This way, workers can identify and resolve process problems before they actually happen. Nevertheless, approved test does not exist yet to show that TPM will have positive effects on OHS.

Unfortunately, no further publications could be found about possible impacts of other LT (i.e. SMED and Kaïzen) on OHS. Table 1.2 shows a brief description about the impacts of some LT on OHS in the manufacturing sector.

Table 1.2 Impacts of LT on OHS in the manufacturing sector

| *Row* | *Author(s)* | *Industry* | *Country* | *Tools* | *Effect on OHS aspect* | *Type of effect* |
|---|---|---|---|---|---|---|
| 1 | Srinivasan et al (2016) | Packaging line in a plant | USA | 5S | Workplace safety improvement | Positive |
| 2 | Jarebrant et al (2016) | - | Sweden | VSM | Intensifying working conditions, increasing the daily workload | Negative |
| 3 | Sakouhi & Nadeau (2016) | - | Canada | Kaïzen | Increasing the rate of MSD among workers | Negative |
| 4 | Filip & Marascu-Klein (2015) | - | Romania | 5S | Workplace safety improvement | Positive |
| 5 | Ramdass (2015) | Clothing | South Africa | VSM, 5S, Kanban | Workplace safety and quality enhancement | Positive |

Table 1.2 Impacts of LT on OHS in the manufacturing sector (Continued)

| *Row* | *Author(s)* | *Industry* | *Country* | *Tools* | *Effect on OHS aspect* | *Type of effect* |
|---|---|---|---|---|---|---|
| 6 | Longoni et al. (2013) | - | - | TPM | Improving safety by reducing the risk of injuries due to machines breakdowns | Positive |

## 1.4 Lean tools adaptation in the mining industries

Unlike the manufacturing sector, there are little information and studies about lean implementation in other industries (Hasle, 2014). This includes the mining sector as well. Some authors pointed out the different nature of the mining environment compared to the manufacturing sector (Flynn & Vlok, 2015; Hattingh & Keys, 2010). They questioned the possibility of successfully integrating lean principles in mining with the same approach as it has been done in the manufacturing (Hattingh & Keys, 2010). Mining environment usually has a dynamic condition with variability, a cyclic process, and notable amount of harmful dusts and gases which can extend the required time for performing each cycle to gain ore at extraction level (Flynn & Vlok, 2015). There are several delays in each cycle due to waiting period for ventilation and evacuation of dusts and gases (resulting from rocks explosion). These delays are a form of waste and should be minimized/eliminated according to the lean principles (examples for each type of waste in mining environment are presented in table 1.3). Other researchers stated that because lean production principles are the same, it should be possible to implement them equally in every industry (Womack & Jones, 2010). There is some evidence about enhancement in mining industries' performance after lean implementation (Castillo, Alarcón & González, 2014; Liu, 2013; Ade, 2012; Dunstan, Lavin & Sanford, 2006). However, limited information exist about the extent that lean can enhance mining companies' productivity without having negative effect on OHS (Nadeau, Morency & Nsangou, 2015; Castillo, Alarcón & González, 2014; Ade & Deshpande, 2012).

As it was explained in section 1.2, the main focus of a lean management system is to eliminate every kind of waste resulting in non-added value activities. Seven different types of waste were defined for the manufacturing sector. Rosienkiewicz (2012) proposed examples for the activities that could be categorized as different types of waste in the mining environment. Table 1.3 shows these examples.

Table 1.3 Examples of different waste categories in the mining sector (Rosienkiewicz, 2012)

| *Type of waste* | *Examples* |
|---|---|
| Delay and waiting | - Trucks idle time due to waiting at rock dumping section<br>- Excavators idle time due to waiting for the trucks' return |
| Overproduction | - Excessive overall production of rocks and ore at the extraction site without considering the maximum ability of the processing plant. |
| Unnecessary movement | - Moving materials and spare parts to a wrong destination<br>- Driving trucks in non-optimized roads |
| Excessive transportation of materials | - Excessive movement of rocks and ore before reaching to the processing plant |
| Extra inventory accumulation | - Storing too little or too much materials in inventory at extraction site |
| Defects in production | - Constant trucks repairing when an overfilling happens |
| Over processing | - Extra drilling for ore |

An important achievement regarding lean implementation in mining industries was reported by Rio Tinto Aluminum management team (Dunstan et al., 2006). Rio Tinto is one of the leading global mining companies with many active exploration and extraction sites around the world, including Australia and Canada. Dunstan et al. (2006) started their work by introducing the major differences between a typical automotive industry (where lean principles emerged from) and a mining environment. In this comparison, the effect of environmental conditions, the amount of produced dusts, and the cyclic nature of mining process were introduced as important factors that are different between a mining and an automotive environment. The extraction procedure in mining is cyclic. It means that certain activities are repeating during each cycle and there are inevitable stops (and waste in the form of delays) between cycles so the setup can be done for starting the next cycle. One of these stops is the required time for ventilation of dusts and gases after each explosion in the underground mining environment. On the other hand, as it was mentioned by Dustan et al (2006), there are little dusts in automotive manufacturing due to ventilation. Apart from these differences, they claimed that the core lean values (e.g. reducing the set up time) are the same in both sectors and thus lean implementation with the same basic approach must be attainable.

Firstly, they chose one of their carbon bake furnace unit in their biggest aluminum plant in Australia as a model site. They wanted to make sure that lean would have positive effects in this site so they can use it as a model for other units within the company. After recognizing the source of wastes in this unit, the management team built a lean information center (LIC) to track daily production performance and to keep the contractors, operators and maintainers constantly aware about the existing issues. The LIC board contained details for lean implementation program, a value stream map of current production process and the steps where non-added activities were happening, and employees' suggestions for enhancement of the process. After identifying different types of waste, they used important lean tools (including 5S and TPM) into their daily activities to eliminate those waste and move towards a lean implementation.

Improvements in many key parameters were reported within few months. For instance, in a two years' time period after commencing the lean implementation, the number of incidents decreased from 154 to 67 and the amount of carbon dusts were reduced from 20% to 6% in the working environment. Although they mentioned a reduction in the number of incidents, however, they did not provide further information about the type of incidents and how lean tools such as 5S and TPM could have positive effects on reducing incident rate. They assumed that these improvements were largely obtained because of lean, however, the actual links between LT and OHS and operational elements were not investigated.

Despite the positive outcomes of this experience, the possibility of considering this unit as a general example for other mining sector is questionable. The selected unit is an open air processing site. It does not have all the environmental conditions of an underground mine. For instance, the level of dust and ambient factors could significantly vary on the underground mine which can extend the spent time for each cycle at extraction stage. This study pointed out the important role of workers and management team in becoming critical problem solvers at their workplace. It can ease the process of lean principles implementation. For this purpose, the authors mentioned that holding continuous educational sessions to keep everyone involved and informed about lean implementation benefits and procedures is essential. However, the workers' level of experience on the selected unit is not specified. Therefore, the impact of people experience on how well lean implementation might go cannot be evaluated.

The other experience of Rio Tinto Corporation was about one of their underground copper mining sites known as Northparkers mine. The main problems in this unit were related to mining equipment and work procedures. These issues frequently affect the extraction process, which is a cyclic process, and slow down the rate of daily progress in underground excavation. The adaptation of lean production in this unit started by creating an information center and letting all workers use it and effectively become involved in the integration process. The goal was to use the flexibility of lean in tracking diversity of issues at the same time and to identify operational problems in every shift. After one month, management team reported positive results as the extraction cycles were enhanced by 56%. Nevertheless, until this day, to the best of this author's knowledge, there is no other published information about the effectiveness of the proposed lean approach in Rio Tinto Northparkers. Therefore, the positive effects of lean in a longer run for this production site cannot be confirmed. Besides, there is no evidence about utilizing other important lean tools such as 5S and TPM and their possible effects on this mine. Another drawback of this experience is the proposed definition for extraction cycle. According to the authors' classification, there are four major steps in each cycle. These steps are: initial drilling, blasting the rocks, cleaning the way, and strengthening the new section. Each cycle can take up to 24 hours. Depending on the mining environment in different places, these steps may change. For instance, the use of explosive is related to the type of the rock and it varies from one place to another. Consequently, generalizing this experience for other mining sites may not be practically possible.

Flamarion, Petter, Antunes & Antonio (2008) investigated the applicability of lean in two different mines within Votorantim mining group in Brazil. Firstly, they started their case study on a fluorspar underground mine using VSM, so the whole production cycle can be studied on a block diagram. They also included the significance of each stage in every cycle based on the required time for each activity. Using this method, they managed to identify the waste more precisely. Unnecessary movement in the drilling stage was recognized as the major source of waste in the cycle. They proposed using brainstorm technique to overcome this problem. Through this technique, they managed a better organization for the drilling team; a team of three drillers. Two of these drillers did the drilling while the third one performed the supportive tasks such as sharpening the drill. This new arrangement provided higher value added time compared to the old one. Eventually, after implementation of lean, a 43.6% raise in productivity was reported. Productivity was measured using a process indicator. This indicator was overall cost of extraction per ton which was reduced due to lean activities. It’s worth mentioning that this study mainly focused on identification and elimination of waste. Other aspects related to miners’ conditions such as OHS and human respects were not considered in it. Furthermore, the interval of time between collections of data before and after lean implementation is not specified so drawing conclusion about effectiveness of this method for other mines with different environment might still need further investigation.

Secondly, they continued their case study on an underground amethyst mine. In the first step, they defined the cycle task for ore extraction in this mine. Similar to what had been introduced by Rio Tinto in Northparkers mine; they followed the same cycle plus two extra steps. These steps were: waiting after the blasting so the produced gases and dusts could be evacuated, and extracting the ores and performing quality control. The main problem in this procedure was the level of dust after the explosion and its possible effect on the workers’ health. Ineffective ventilation plus drilling without humidity were main sources of waste in this cycle. It caused excessive waiting time for removal of dust and gas. Finally, by proposing a new ventilation system and a wet drilling process, reduction in level of dust in ambient and other enhancements in the process productivity were reported. Nonetheless, no measurement has been made to show the link between miners' health condition and the level of dust in the air and how lean integration could help to enhance OHS in miners' workplace.

Two years later, Bäckblom et al. (2010) published a conceptual report about future challenges in mining industry. It was an attempt to unite Polish and Swedish major mining industries together for creating a vision about deep underground mining in the near future (i.e. year 2030). They tried to identify the main problems in the current situation and then proposed priorities for implementation of lean in the mining sector. According to their conclusion, in the underground mining, having continuous procedure is vital for integration of lean. Needless to say that, with a continuous process system, a significant source of waste in the form of waiting time can be eliminated. They mentioned that based on their current technologies and equipment, a more continuous and reliable process is not obtainable and thus lean mining may not be fully attained. Therefore, a significant improvement in the equipment is necessary if lean mining is going to be pursued. They also included social aspects and cultural behaviors into their vision. They summarized that a desirable lean production system should be integrated with human social conditions. Moreover, workers' safety can be maximized by minimizing workers' access to the operational site through automation of the equipment. So far, no further results have been published about their possible progress in implementing lean in mining or applying new technologies for making underground mining process more continuous.

Based on what had been proposed about lean mining approaches by Bäckblom et al. (2010), employee's cultural behavior and its impact on lean mining integration was studied by Sanda, Johansson, J. & Johansson, B. (2011). They defined mining culture of employees as the values, judgments, and opinions that employees commonly rely on. They argued that ignoring or missing this lean culture could be a reason for failure of many companies to achieve positive results while applying lean tools. In other words, lean tools were not effective because the required lean mining culture for stabilizing it was not included. They considered two different set of data for their research. One was from historical point of view and was collected from wide range of reports. These set of data were gathered to show evolving of mining from an old human based conditions to a more technological process based. The other set of data, named '*actual data*', was obtained from an existing underground mine located in Sweden. They collected the actual data by holding interviews with miners and observing an operational site during different shifts. According to the results, the emphasis of the traditional view of workers about mining was about being more cautious in the mining environment, having knowledge about the rock due to directly extracting them, and relying more on doing the 'physical job'. Teaching these traditional mining approaches to new miners and integrating the old culture with lean mining philosophy could help miners to feel empowered by considering their opinions. Moreover, adding personal experiences of miners into what was proposed by Bäckblom et al. (2010) as future lean tasks in mining environment, may facilitate the process of lean implementation in the underground mining. The extent which miner's knowledge transition can be helpful for integration of lean was not measured in this study. Hence, the reliability of this method for other underground mines may not be clear. Besides, the sample size and data collection method were not specified in their report. Consequently, generalizing the findings of this study needs further information.

Castillo et al. (2014) studied the impact of lean mining on project' performance enhancement. They conducted their case study in three different projects in a Chilean's underground mine. In order to increase the validity of the study, they selected those projects that were commenced in the same underground mine and were organized and managed by the same company. Moreover, all of the selected projects would last at least one more year from the date of executing this study. This would allow the results to be compared. All the projects were on the construction phase and were performed by the same contractor. Out of three projects, one of them had already started implementation of lean for a month, but the other two projects had not started yet. The integration of lean was commenced with a variety of tools (e.g. VSM, 5S, and Kaïzen). The whole study took place within 8 months. Initially, the key issues were introduced as: time usage, planning, degree of resources' availability, and applied system for management. For resolving these issues and enhancing the project's program through lean, following indicators were defined: improvement in planning, enhance communication within contractors and other relevant parties, decrease waste due to operation, unify teamwork, and enhance agreements between parties. Eventually, by performing qualitative and quantitative analysis for measuring the degree of enhancement for proposed key issues after implementing lean, positive results were reported. Authors stated that promising attitude among workers toward continuous enhancement by lean mining was detected in all of the undertaken case studies. On the other hand, few drawbacks were reported during implementation of lean. For instance, intensifying of working conditions for the employees in the beginning of the implementation was a challenge for the managers. They needed to balance workers' daily schedule by proposing a firm work plan. Findings of this study; nevertheless, are limited to a short time period. For assuring that lean mining could have continuous positive effects on a long run, further investigations are required. Besides, because of the small sample size, generalizing outcomes of this study is limited. Furthermore, economic impact of lean implementation was not studied in this research and other studies need to be conducted to evaluate this aspect.

Chlebus, Helman, Olejarczyk & Rosienkiewicz (2015) carried out a study about integration of TPM in an underground copper mine. This study was the first attempt for integration of lean mining in Poland. Initially, they encountered lack of guidelines for this process due to absence of a coherent methodology for lean mining implementation. To tackle this problem, they introduced three main bases for applying TPM in mining environment: workplace enhancement, development of standards, and scheduled maintenance. They also categorized four main reasons for possible malfunction of machines in mining. This included heavy environmental conditions as well. They managed to record more than 600 failures of machines through their pre-design data collection sheets in less than three months. Analyzing these data revealed that most of the failures happened due to lack of spare parts. By distributing a survey among miners and using historical data, a list for most frequently used spare parts was created. Eventually, by designing standards for the repairing procedure of machines using TPM and 5S, a reduction in the average repair time were obtained (the repair time almost became half). Authors stated that their designed standards' template for repairing process could be generalized and used in every mine for integration of TPM. However, they did not specify the flexibility of these standards to different mining environment utilizing dissimilar machines. Additionally, no measurement about the economic impacts of this implementation for this mine had been made. Therefore, the actual outcome of using TPM regarding economical aspect in this underground mine is not clear.

Later, Lanke, Ghodrati & Lundberg (2016) conducted a comparative study about different lean implementation's techniques across different sectors to find the most relevant and suitable methodology for lean implementation in Swedish mining industry. To obtain better results, they defined three main elements as the requirements for the industries to be met: having similarity with mining sector in form of manufacturing process (i.e. to be a process industry), following the same objectives as mining for integration of lean, and having a clear methodology for obtaining those objectives. Like previous studies, they encountered insufficiency in available standard methods for implementing lean in mining. To resolve this issue, they chose four processing industries' standards for final evaluation:

- A food manufacturing approach toward lean integration based on enhancing customer satisfaction, staying competitive with other food companies through continuous quality assurance process, and performing constant quality control to ensure that the food production procedure will follow the laws;
- An Indian automotive standard known as Mahindra Quality Way (MQW) which is a quality control method developed based on 'Deming Wheel' concept. The main goal in this approach is to fulfill the objectives of company and stakeholders through involvement of all employees and constant monitoring of their progress;
- European Foundation of Quality Management (EFQM) used by some processing companies across Europe. The EFQM main objectives are to introduce a way for implementation of Kaïzen and identifying the areas which require more attention and those activities that should be marked as redundant;
- Production Assurance Program (PAP) applied by a Norwegian gas & oil company. The PAP relies on decreasing uncertainty of system through improving reliability of the equipment.

Authors did not specify the reasons for selecting these methods and why other similar standards had not been considered. Among these methods, PAP in oil and gas industries relies on decreasing uncertainty of system through improving reliability of the equipment. After investigation of each method, they concluded that PAP had the most similarity with the mining sector and can be used as a standard method for implementation of lean. Nonetheless, the effect of this method on lean mining has not been tested yet. Other studies are required to evaluate the impacts of PAP on implementing lean tools based on socio-technical aspect.

Maunzagona & Telukdarie (2017) undertook a study to find out about the possible link between using VSM and productivity improvement in South African diamond mining sector. For this purpose, they constructed the current state of VSM through a case study. In the next step, they developed the improved and optimized VSM for producing diamond through a computer simulation. Based on their simulation results, using VSM as a LT can reduce the cycle time for producing diamond around 10%. This could have direct impact on increasing the production rate and profit of the company. However, the final results has not been tested yet and no publication could be found showing the actual impact of using the optimized VSM on the production rate and cycle time.

Unfortunately, to the best of this author's knowledge, no further published information about mining companies' experiences with lean integration could be found. So far, according to the reviewed literature, a holistic lean approach in the mining sector, which can combine the technical aspects of lean with the OHS aspects, does not exist. Further investigations are required to fill this gap and propose a preliminary road-map for integration of lean tools into mining industries. Table 1.4 shows the results of recent case studies about implementing LT in mining industries.

It is important to mention that implementation of lean mining is required for establishing Industry 4.0 principles in a company (Satoglu, Ustundag, Cevikcan & Durmusoglu, 2018). Industry 4.0 is a logical next step for implementation of new technologies in a plant (e.g. reaching to a digitally organized production). However, before the mining sector in Canada start establishing Industry 4.0 principles, it is recommended that they integrate lean mining first to ensure elimination of waste in their process (Nadeau & Landau, 2017).

Table 1.4 Review of recent case studies regarding LT implementation in the mining sector

| *Row* | *Author(s)* | *Year* | *Country* | *Type* | *Tools* | *Effect* |
|---|---|---|---|---|---|---|
| 1 | Dunstan et al. | 2006 | Australia | Aluminum | LIC, 5S, TPM | Performance improvement (on early stage of lean implementation) |
| | | | | Bauxite | LIC & 5S | Cycle times reduction |
| | | | | Underground Copper mine | LIC | 56% enhancement in the cycle time |
| 2 | Flamarion Klippel et al. | 2008 | Brazil | Fluorspar | VSM, brainstorm | 43.6% raise in productivity |
| | | | | Amethyst | VSM | 16.6% improvement in the process added value time |
| 3 | Ade & Deshpande | 2012 | India | Coal | VSM, Cellular manufacturing | 16.8% increase in production rate |
| 4 | Liu | 2013 | China | Coal | 5S | 16.5% reduction in processing time |
| 5 | Castillo et al. | 2014 | Chile | Copper | VSM, 5S, Kaïzen | Enhancement in project performance and productivity |
| 6 | Chlebus et al. | 2015 | Poland | Copper | 5S, TPM | Decrease in average repair time |
| 7 | Maunzagona & Telukdarie | 2017 | South Africa | Diamond | VSM | Possible 10% reduction in cycle time |

## 1.5 Lean tools and their impacts on OHS in mining industries

In this section, a literature review about the impact of lean mining on workers' health and safety will be carried out. The main objective of this section is to find the links between lean tools and OHS conditions in the mining sector. According to a literature review study performed by Nadeau et al. (2015), there are certain challenges in the mining environment that could cause OHS related issues while implementing lean (e.g. uncertainty and variability). Despite these challenges, lean can have positive impacts on OHS by involving workers in their job, enhancing the workers' training, and proposing improved tasks for them (Nadeau et al., 2015). However, the available relevant results about lean mining integration are still insufficient. Therefore, implementation of lean concept in the mining sector regarding OHS issues still needs more in depth investigation.

As it has been discussed thoroughly in the previous section, the main focus in the published studies about lean mining was to eliminate different type of waste to improve the productivity and profit. To the best of this author's knowledge, very few studies which focus on investigating impacts of lean tools on OHS in mining environment have been published yet. However, the available results of these studies are usually non-detailed and do not investigate the possible links between OHS and lean tools (Dunstan et al., 2006;  Flamarion Klippel et al., 2008;  Ade & Deshpande, 2012; Vaněk, Mikolá & Pomothy, 2015).

For instance, Dunstan et al (2006) reported a 57% decrease in the rate of incident among miners of Rio Tinto aluminum mine after implementing lean using LIC, 5S, TPM. However, they did not provide further explanations about how using these lean tools could reduce the incident rate among miners.
Flamarion Klippel et al (2008) reported reductions in the level of dusts during extraction of amethyst in an underground mining environment using VSM. They concluded that this reduction could enhance miners' health and safety. However, they didn't mention to what extent VSM can actually improve the miners' health in this specific condition.

Ade & Deshpande (2012) studied the possibility of adding a man rider system (a sort of mechanized transportation system) for miners to eliminate delays in movement of miners inside an underground coal mine in India. They used VSM and cellular manufacturing as LT to implement this new miners' transportation system based on the lean mining concept. According to the result, the productivity at extraction level increased. They also mentioned a possible reduction in miners' fatigue rate due to less unnecessary movement. Although based on their results, reduction in miners' effort for transporting from one place to another for performing their daily activities is obtainable; however, the link between used LT (VSM and cellular manufacturing) and miners' fatigue has not been clearly specified. Table 1.5 shows impacts of LT on OHS in mining environment according to the literature.

Table 1.5 Impacts of LT on OHS in the mining sector

| *Row* | *Author(s)* | *Year* | *Country* | *Type of mine* | *Tools* | *Effect* |
|---|---|---|---|---|---|---|
| 1 | Dunstan et al. | 2006 | Australia | Aluminum | LIC, 5S, TPM | 57% decrease in the rate of incident among miners |
| 2 | Flamarion Klippel et al. | 2008 | Brazil | Amethyst | VSM | Possible enhancement in miners health due to reduction of dust's level |
| 3 | Ade & Deshpande | 2012 | India | Coal | VSM, Cellular manufacturing | Possible reduction in the required effort for moving by miner after installation of a man rider system |
| 4 | Vaněk et al. | 2015 | Czech Republic | Coal | Kaïzen | Possible enhancement in miners safety and health conditions |

## 1.6 Research question

Discovery of several types of minerals (more than 60 different types) throughout Canada made mining industry a major contributor to the economic growth of this country (Brendan, 2016). Nowadays, Canada is a leading producer of minerals around the globe. Besides, Canada is among major producers of few key materials such as: uranium, nickel, gold, and diamond (Brendan, 2016). In today's competitive economy, reducing waste and cutting non-value added activities is a must for those companies that want to stay financially successful (Flynn & Vlok, 2015). As it was discussed, lean is an effective approach towards gaining profit and elimination of wastes in the mining sector. The implementation of lean into mining; however, could be a challenge due to high level of uncertainty and hazard in this sector compared to other industries

(Badri, Nadeau & Gbodossou, 2012). In addition to that, lean mining in Canada is still emerging, meaning that mining companies which are implementing LT are still at early stages of lean lifecycle. Moreover, there is not enough information in the literature about the actual transition stages from a non-lean to a lean mining extraction system. Therefore, the research problem in this study will be to find out which lean tools might be used and how these tools can be implemented in the Canadian mining industry so their possible negative effects on miners (from OHS point of view) can be controlled. To set up a more realistic goal, this thesis' focus will be on investigating the possibility of integrating LT in the Canadian underground gold mining sector on the extraction level. The proposed research problem can be divided into two sub-problems as follow:

- What type of lean tools should be selected for proper integration of lean in the underground mining at early stages of lean implementation at extraction level?
- How to implement the chosen lean tools to improve the economic in the Canadian underground gold mining at early stages of lean implementation at extraction level without creating negative influences on miners' health and safety? (an OHS approach)

It is expected that by finding answers to the presented research problem, a comprehensive and useful preliminary road-map for integration of lean into Canadian underground gold mining at extraction level can be developed. It will aid the management team in the mining sector to know which particular lean tools they should use. Moreover, it will help them to make sure they maintain a safe mining workplace and environment and improve the extractions rate and profits at the same time.

## 1.7 Research Objectives

Based on what was proposed as the research question, following objectives are to be met in this research:

- The first objective of this research is to identify proper lean management tools and propose an approach to introduce these tools into the Canadian mining sector.
- Another important aim of this study is to develop a comprehensive and useful preliminary road-map for integration of lean management into Canadian underground gold mines at extraction level at early stages of lean implementation considering OHS regulations.

It is important to remember that implementation of LT needs to follow the existing regulations and principles of occupational health and safety (OHS) in the mining workplace in Canada. Moreover, it must be noted that lean mining is starting up in Canadian mines and to the best of our knowledge no experience and no documented information about implementing a whole lifecycle of lean yet could exist. Consequently, doing a literature review about the experience of other sectors such as manufacturing about the whole lifecycle of lean implementation and contextualizing the results for mining sector in Canada can be helpful to achieve the objective of this thesis.

# CHAPTER 2

# THESIS RESEARCH METHODOLOGY

In this chapter, we discuss the research methodology of this thesis. The main aim of this chapter is to define the approach and the tools that will be used to address two objectives of this thesis and answering the research question (which were set out in the previous chapter). As first step, the basic design of this research will be established and methodological choices will be presented (section 2.1). In the following section, selection of independent and dependent variables will be discussed (section 2.2). Different data gathering methods used in this study will be presented afterwards (section 2.3). Finally, statistical methods for analyzing obtained data will be described (section 2.4).

## 2.1 Research design

There are two main approaches in collecting data: qualitative and quantitative. Quantitative approach usually includes numerical data while qualitative data are naturally non-numerical. Each approach has its own benefits and limitations. In general, quantitative approach can be used when the researchers seek to carry out statistical analysis, find accurate and exact data and result, and want to analyse a big sample size. On the other hand, qualitative approach is most useful when obtaining in-depth knowledge about the studied subject is desired or the size of studied sample is not important (Creswell, 2002). In the following section, justifications about choosing qualitative approach as the research design of this thesis will be provided.

### 2.1.1 A qualitative exploratory approach

It is crucial to keep in mind that the lean concept was originated from Toyota Car manufacturing Company. Each company has its own management system and working environment and thus lean principles should be implemented based on these conditions within every company (Sakouhi & Nadeau, 2016). Without considering these criteria, implementation of lean might not be successful. Therefore, a unique method for adopting the lean approach which can be applied in every mining company similarly, does not exist.

According to the literature reviewing section, implementation of lean tools has been extensively studied in the manufacturing sector. There are publications proposing a road-map for the integration of lean (Belhadi & Touriki, 2016; Mostafa, Dumrak & Soltan, 2013), the lean implementation lifecycle and suggested tools to be used in each stage (Egbue, Wang & Eseonu, 2014), and the links between using lean tools and occupational health and safety (OHS) conditions in the working environment (Srinivasan, Ikuma, Shakouri, Nahmens & Harvey, 2016; Jarebrant, Winkel, Hanse, Mathiassen & Öjmertz, 2016; Sakouhi & Nadeau, 2016; Longoni, Pagell, Johnston & Veltri, 2013). The reported results were not always positive. For instance, Sakouhi & Nadeau (2016) studied the possible link between musculoskeletal injuries (MSI) issues (as an OHS indicator) and continuous improvement (as a lean tool) among workers in a manufacturing company in Quebec. They concluded that the lean activities in that company were short-lived and non-sustainable over time. Furthermore, workers often reported that they had discomfort related to MSI issues after an organizational change. It means that, in this specific case, integration of lean principles did not always reduce the level of MSI related issues among workers in the long run.

On the other hand, these types of studies are scarce in the mining sector (Nadeau, 2015). To the best of our knowledge, no published articles or technical reports proposing a road-map for implementation of lean mining at different stages of lean implementation yet exists. Moreover, little information was found in the literature regarding the links between integration of lean tools and the OHS issues in the mining environment (Castillo et al., 2014; Shukla & Trivedi, 2012). Considering lack of sufficient information about the studied subject, choosing a qualitative approach seems to be more beneficial for addressing the research question. Creswell (2013) explained the conditions for which a qualitative approach might fit better as below:

> "*If a concept or phenomenon needs to be understood because little research has been done on it, then it merits a qualitative approach. Qualitative research is exploratory and may be needed because the topic is new or the*

> *topic has never been addressed with a certain sample or group of people."*
> (Creswell 2013, pp.18)

Since little information exist about lean mining tools and their links with OHS issues and this subject is still poorly elucidated, exploratory research is the type of study to be preferred in this case (Creswell, 2013; Fortin, 2010). The first step in the exploratory research approach is the identification of the problem, which then allows elaborating the underlying questions to be researched (it was done in the first chapter). The methodological choices then guide the development of the research. This is followed by the collection of data which, in this thesis, is carried out in two stages:

1. A review of the literature initially helps identifying factors and conditions that may reveal the link between lean tools, economic and OHS indicators in the mining environment. It also allows addressing one of the research objectives of this research (i.e. selecting proper lean tools at different stages and lifecycle of lean implementation in Canadian mining industries while considering OHS issues);
2. Semi-directed interviews with Canadian experts in the mining sector.

The last stage of the exploratory research in this thesis is the processing of obtained data using different statistical methods. Fig 2.1 shows the above mentioned stages of an exploratory research design. After the fourth stage, the results would be available to be interpreted and then answering the research question and addressing objectives of this thesis would be possible.

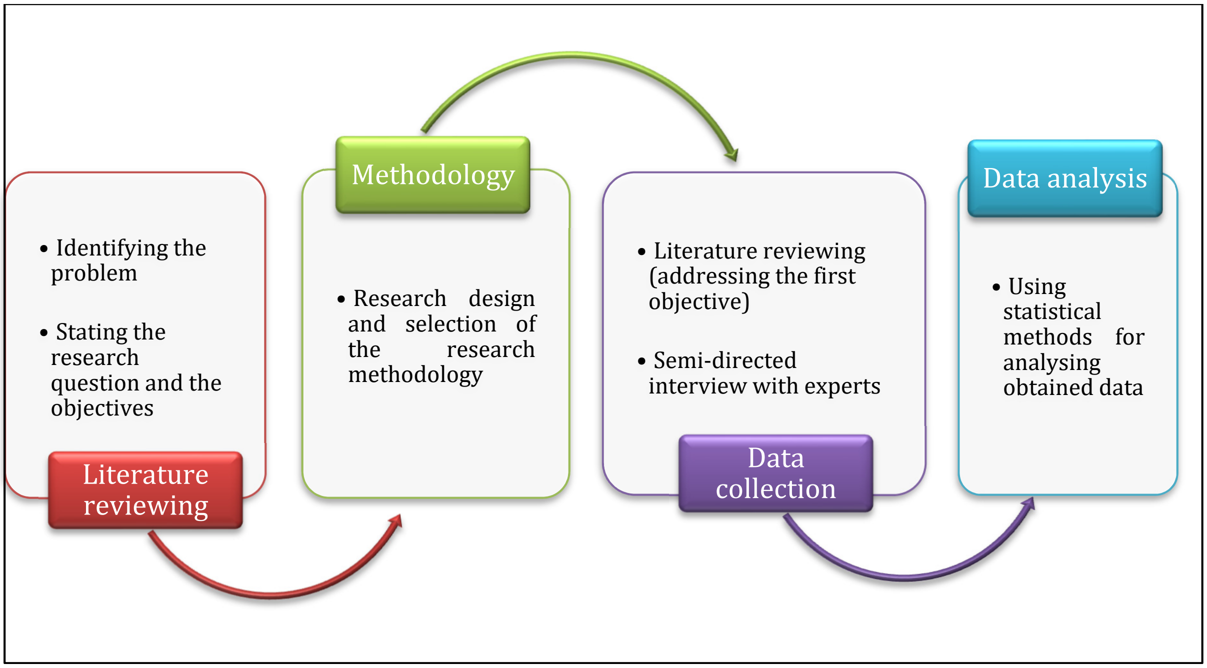


Figure 2.1 Exploratory research design of this thesis

### 2.1.2 Methodological choice: using expert elicitation

Based on a study by Creswell (2007), there are five methods for conducting a qualitative study. These methods are: narrative, ethnography, phenomenological, grounded theory, and case study. Each method focuses on a certain condition, sample group, and uses different ways for collecting data. The narrative method includes individuals and their life stories, in ethnography the main focus is discovering culture, phenomenological method interviews people who have information about a certain phenomenon, grounded theory method focuses on developing theory based on field data, and case study is based on obtaining data from a company, people or event. An effective way to address the objectives of this research is to use expert elicitation. As a qualitative approach for obtaining data, expert elicitation protocol can be categorized as a way to undertake the ethnography and case study method (Creswell, 2007). Expert elicitation is about obtaining and developing a representative for the experts' opinions and ideas (O'Hagan et al., 2006). It includes a systematic procedure for analyzing the experts' ideas when uncertainty exists due to the lack of available information (Slottje, Sluijs & Knol, 2008). There could be many different reasons for using expert elicitation method (Veen, Stoel, Zondervan-Zwijnenburg & Schoot, 2017). For instance, adding data to an existing sample (Zondervan-Zwijnenburg, Schoot-Hubeek, Lek, Hoijtink & Schoot, 2017), enhancing the existing information, and performing a sensitivity analysis to predict the missing information (Veen et al., 2017) are few examples of the situations where using expert elicitation is recommended. Using this method is also considered in the literature when information about a specific factor in a study are insufficient (Fischer, Lewandowski & Janssen, 2013), and when available information about the studied subject are scarce or non-existent (Hald et al., 2016). O'Hagan et al. (2006) mentioned a variety of different examples where expert elicitation methodologies can be used. Deepen understanding about the impact of lean tools on OHS issues, as well as the economic indicator in Canadian mining environment is an important aim of this study. To achieve this deepening of knowledge, focusing on the expert elicitation as a research method is an appropriate choice. Gavrilova & Andreeva (2012) mentions that the main strength of an expert elicitation method is to provide an in-depth analysis of the phenomena in its context.

Like every scientific method, there are certain limitations in using an expert elicitation approach. Drescher et al. (2013) explains these limits as follow:

"*The knowledge held by expert practitioners is too valuable to be ignored. But only when thorough methods are applied, can the application of expert knowledge be as valid as the use of empirical data. The responsibility for the effective and rigorous use of expert knowledge lies with the researchers."* (Drescher et al., 2013, p. 1)

Factors such as overconfidence, conflict of interest, being biased about the studied subject, and problems related to properly transferring the knowledge can be considered as common mistakes among the experts which can lead to obtaining limited results (Hemming et al., 2018; Soll & Klayman, 2004; Gigerenzer & Edwards, 2003; Burgman, 2001). Moreover, asking unrelated and ambiguous questions and wrong choice of elicitation method can intensify this situation (Hemming et al., 2018; Shanteau, Weiss, Thomas & Pounds, 2002). Setting boundaries on the studied subject can help to reduce these disadvantages. As it was explained in the research question section, by placing boundaries on the research, the focus of this thesis will be: investigating the possibility of lean tools selection and implementation in Canadian underground gold mining on extraction level at early stage of lean integration with OHS considerations.

Selection of a gold mine over other type of ores was made because of economic reasons. According to a published report by the mining association of Canada (MAC), gold held the record among the other ores as the most profitable ore for exporting to other countries by over 17 billion dollars trade value by the end of 2013. This is around 20% of all Canadian exported goods every year. However, the global Gold price has been slightly declining in the past 5 years as it dropped from $1310 per ounce in 2014 to $1265 per ounce in 2019 (Syed Zwick, Hélène & Sarfaraz, 2019; Marshall, 2016). Furthermore, process and labour costs for extracting gold ore are usually higher in underground mining compared to open-pit mining (due to a more complex extraction process because of variability, type of rocks, and a more challenging working environment). Consequently, improving productivity by using different methods, such as lean mining, seems to be a good solution to overcome this issue and keep the gold mining significantly profitable.

Now that the boundaries of the study have been determined, the type of expert elicitation must be selected. There are several different ways for conducting expert elicitation study according to Gavrilova & Andreeva (2012). Each way has its own merits and limitations. For a research problem with a little or no earlier background study, an interview using questionnaire can provide the opportunity to gain some background information about the new topic. This type of data gathering is flexible and can address a wide range of research questions. A limitation for this type is that the sample size is usually small and therefore generalizing the findings based of the sample size to a large population is not always possible. Hill (1998) mentioned that for exploratory studies, sample sizes below 10 can be considered as small. As it was explained before, lean mining method could differ from one company to another due to different organizational management system. Therefore, this study does not attempt to find a unique solution for lean implementation which could be used in every mining company. Instead, it focuses on distinguishing the type of tools (and their links with OHS issues) which could be used for implementing lean in the Canadian underground gold mining company at extraction level, generating a preliminary road-map for this implementation and finally deepen the knowledge about lean mining in Canada. Although the results of this study might not be generalized; however, it could be used as a basis for further studies about the same subject with a different approach to reach to a more generalized result about lean mining. It is worth mentioning that before starting any communication with the experts, the approval of the Ethics Committee of École de technologie supérieure (ÉTS) was gained in September 2018. This approval was also maintained through the Ethics Committee of Université du Québec en Abitibi-Témiscamingue (UQAT). The final certificate is presented in Appendix IV.

## 2.2 Introducing variables

The main aim of this section is to introduce all the important variables that will be studied in this thesis. This includes selecting one independent and two or three dependent variables on which the related data will be gathered and the links between these variables will be investigated. This limit for the number of variables is set to make sure that this master thesis will meet its objectives in a time allowed to complete this project without involving too many variables which cannot be studied in a single thesis.

### 2.2.1 Independent variable

As it was discussed in the previous chapter, LT are effective and necessary for implementation of lean concepts in an organization. Referring to the research question, an important objective of this study is to identify which lean tools should be used at different stages of lean implementation in the Canadian mining industries considering OHS issues. One way to find an answer to this question is to study the most used lean tools and their possible impacts on OHS and economic factors. Table 2.1 shows the selected lean tools (SLT) based on what had been proposed in the literature about lean mining at different process levels (Chlebus et al., 2015; Nadeau et al., 2015; Castillo et al., 2014; Liu, 2013; Ade, 2012; Dunstan et al., 2006). This includes Value Stream Mapping (VSM), Five S (5S), Kaïzen, Total Productive Maintenance (TPM), Single-Minute Exchange of Dies (SMED), and Lean Information Center

(LIC). These tools will be used as the independent variables and their impacts on OHS and economic indicators will be investigated.

A limitation for this choice is that all of these tools were selected based on the previous experience of other mining companies outside of Canada with different mining environments and rock characteristics compared to Canadian mines. Consequently, these selections might not be the best possible choice and there might be other tools which have not been considered within the literature but fit well in Canadian mines for implementation of lean.

Table 2.1 Selected lean tools as the independent variable

| *Type* | *Group* | *Main tools* |
|---|---|---|
| Independent Variable | Set of lean tools | VSM / 5S / Kaïzen / TPM / SMED / LIC |

### 2.2.2 Dependent variables

There are two important categories regarding dependent variables in this study: OHS and economic group. There could be many different indicators for each mentioned category according to the literature (Donoghue, 2004; Martínez Sánchez & Pérez Pérez, 2001). To gain a better idea about choosing the most relevant indicators, each category is discussed separately.

#### 2.2.2.1 OHS indicators

Donoghue (2004) divided OHS issues in the mining field into five major groups: physical, chemical, biological, ergonomic and psychological. For each group he introduced the most important indicators. These data were obtained from reviewing published case studies and reports about mining hazards and health risks in this environment. Table 2.2 presents his findings. Only two indicators may be chosen as the dependent variables due to limitation of this study as a master thesis. For this purpose, current issues related to OHS in Quebec gold mining sector were identified according to the published online report by the *Commission des*

*Normes, de l'Équité, de la Santé et de la Sécurité du Travail* (CNESST). These results can be seen in Figure 2 (CNESST, 2011) According to this figure, physical vibration, struck by an object and body reaction have the highest rate of causing accidents and injuries among miners in Quebec gold and silver mines between 2002 and 2011 (CNESST, 2011). These indicators are responsible for almost 67% of all the injuries and OHS problems in this sector. However, before choosing an OHS indicator as the dependent variable, its logical link with the independent variable (i.e. SLT) must be established at first. This will ensure that the selected variables will contribute to answering the research question and fulfilling the objective of this study. SLT purpose is to enhance the extraction process by eliminating different forms of wastages, thus only those OHS indicators that have direct links with the process might be considered.

According to a published report by Institut de recherche Robert-Sauvé en santé et en Sécurité du travail (IRSST), excavators, scrapers and bulldozers were identified as the main source for causing body vibration among miners (Marcotte, Ouellette, Boutin & LeBlanc, 2011). Based on the Canadian occupational health and safety regulations, the vibration problems must be eliminated at the source in a preventive way[1]. Therefore, the methods for eliminating body vibration in the mining environment are mainly developed in a controlling way (e.g. reducing the exposure of miners to the source of vibration, levelling the operator's seat on the vehicle to reduce the vibration). Consequently, vibration will not be chosen as an OHS indicator in this study since that it is more of a human factor design based issue rather than a process problem. The CNESST defines *«struck by an object»* as the miners' body damages and injuries due to striking by an object. This definition applies only when the movement at the origin of the contact is primarily attributable to the object rather than to the miner (e.g. getting struck by rocks, flying or slipping object). It excludes strikes by vehicles or mobile equipment as it

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[1] "*An employer shall ensure that all motorized materials handling equipment in use is designed and constructed so that any employee required to operate or ride on it will not be injured or its control will not be impaired by any vibration, jolting or uneven movement of the materials handling equipment*." – Canadian OHS regulations SOR/88-632, s. 58; SOR/96-400, s. 1. § 14.10 (2002)

should be prevented at source according to the Canadian OHS regulations[2]. Therefore, this OHS indicator is more affected by the extraction process which might be altered by SLT. Considering the importance of this OHS issue as one of the major reasons for causing injuries among miners in Quebec (Fig 2.2), this indicator will be selected as one of the OHS indicator for this study. According to the CNESST classifications, among all the miners, those who work as drillers and driller's assistance, equipment operators and handlers, miners specialized in transport and loading, and motor vehicle mechanics and repairers are more prone to be struck by an object during their daily activities (CNESST, 2011).

The third significant OHS issue in Quebec's gold and silver mines is body reaction (Fig 2.2). Based on the proposed definition by CNESST, it refers to injuries and damages caused by reaction of miner's body under certain conditions:

- A non-repetitive movement of the body (without effort);
- Having imposed stress or tension on a certain part of the body;
- The adoption of an unnatural posture or voluntary or non-voluntary movements, due to sudden noise or efforts to recover from slippage or loss of balance.

The body reaction can cause damages to different parts of miners' bodies (e.g. injuries to the muscles, tendons, ligaments and others). This is another process-affected OHS issue which can be minimized by improving the extraction process. This improvement might be possible using SLT while implementing lean mining concept. Therefore, there might be a possible process based link between SLT and body reaction in the mining environment. This indicator will be selected as the second OHS indicator for further investigation. Based on the CNESST classifications, those miners who work as drillers and driller's assistance, and miners specialized in transport and loading are more prone to body reaction during their daily activities (CNESTT, 2011).

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[2] "*The employer shall equip the motorized materials handling equipment with a protective structure of such a design, construction and strength that it will, under all foreseeable conditions, prevent the penetration of the object or load into the compartment or position occupied by the operator.*" – Canadian OHS regulations SOR/96-400, s. 1. § 14.4(1), (2002)

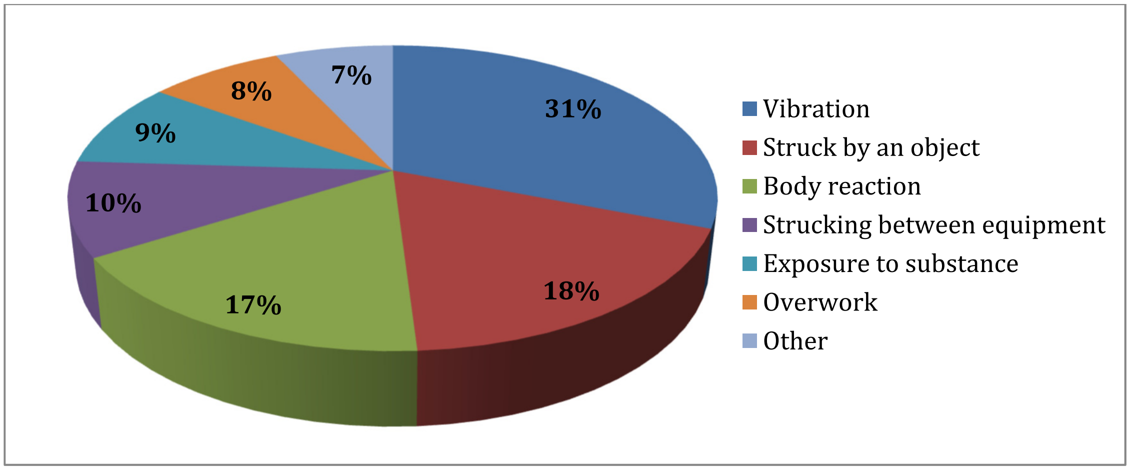


Figure 2.2 Type of injuries in gold and silver mines in Quebec region between 2002 and 2011 (based on the information retrieved from CNESST official website), (CNESST, 2011).

Table 2.2 Important indicators for OHS hazards in mining environment (Donoghue, 2004).

| *Dependant variable (1)* | *Group* | *Indicators* |
|---|---|---|
| OHS | Physical | Struck by an object |
| | | Fire |
| | | Explosions |
| | | Falls from height |
| | | Noise |
| | | Vibration |
| | | Heat and humidity |
| | | Body reaction |
| | | Barometric pressure |
| | Chemical | Crystalline silica |
| | | Diesel PM exposure |
| | | Cyanide solvent |
| | | Mercury |
| | Biological | Legionella (Cooling tower) |
| | Ergonomic | Cumulative trauma disorder |
| | | Overhead work |
| | | Fatigue |
| | | Sleep deficits |
| | Psychosocial | Drug and alcohol abuse |
| | | Remote location |
| | | Morale |

#### 2.2.2.2 Economic indicator

According to a literature review by Martínez Sánchez & Perez Pérez (2001), there are four main groups of economic indicator of lean implementation into the manufacturing sector. These groups are: quality and quantity, flexibility, lead time and cost. Table 2.3 shows related indicators for each group. It is important to consider the different environment and nature of mining compared to the manufacturing sector before choosing any economic indicator as dependent variable. Like many other sectors, an important economic indicator in the mining field is productivity (Martínez Sánchez & Perez Pérez, 2001). A definition for productivity in the mining field at the extraction level is the amount of extracted ores versus the amount of extracted rocks. Increasing this ratio will lead to productivity enhancement. Considering hard rock mining in Canadian underground mines, the productivity index is tied up with the horizontal and vertical advance rate per day while extracting ores (Pareja, 2000). Despite the fact that new equipment and technologies with more power and efficiency have been introduced to the underground mining field, the advance rate has been constantly declining in the past few years as the extraction process in the underground mines go deeper. Consequently, the operation becomes more costly, the rocks become harder to remove, and the working environment becomes hotter for miners (Pareja, 2000). All of these reasons affect the daily advance rate and thus drop the overall productivity. The process improvement using SLT can have positive effects on the daily advance rate which will improve the productivity of the whole extraction process. Eventually, the daily advance rate will be chosen as the economic indicator (as an important indicator for underground gold mining and in accordance with the research question). Table 2.4 lists all the selected variables in this thesis.

Table 2.3 Major indicators for economic aspect of lean manufacturing (Martínez Sánchez & Perez Pérez, 2001).

| *Dependent variable (2)* | *Group* | *Indicators* |
|---|---|---|
| Economic | Quality & Quantity | Defect control rate |
| | | Task rotation frequency |
| | | Supplier delivery rate (JIT) |
| | | Supplier delivery and company`s production integration |
| | | Production lot size |
| | | Rate of suppliers` company visit by technicians |
| | | Percentage of recorded procedure for production |
| | Flexibility | Employees involvement in teamwork rate |
| | | Number of performed tasks as teamwork |
| | Lead time | Number of dedicated people to quality control |
| | | Idle time for machines due to malfunctions |
| | | Number of suggestion made for suppliers |
| | | Percentage of parts co-designed with suppliers |
| | | Frequency which information is given to employees |
| | | Percentage of preventive maintenance over total maintenance |
| | Cost | Employees rotating tasks within the company rate |
| | | Lead time of customers` order |
| | | JIT delivery between sections in production line |

Table 2.4 List of independent and dependent variables of this study

| *Type* | *Group* | *Indicator(s)* |
|---|---|---|
| Independent Variable | Set of lean tool | VSM / 5S / Kaïzen / TPM / SMED / LIC |
| Dependent Variables | OHS | Struck by an object |
| | | Body reaction |
| | Economy | Advance rate per day |

## 2.3 An introduction for data gathering methods

The first essential step toward obtaining data would be to identify the source of information and to define methods for retrieving them. As it was explained in section 2.1 (research design section), collection of data will take place in two levels including literature reviewing and holding semi-directed interview with Canadian experts. Each of these methods will be discussed individually in the following section.

### 2.3.1 Literature reviewing

According to the first chapter and what was explained in section 2.1.1, unlike manufacturing sector, studies about proposing a road-map for the integration of lean, identifying different stages of a lean lifecycle and suggested tools to be used in each stage are scarce in the mining environment (Belhadi et al., 2016; Nadeau et al., 2015; Egbue, Wang & Eseonu, 2014; Mostafa et al., 2013). To understand different stages of lean mining lifecycle and discovering which lean tools can be used in every stage, a literature review has been carried out. Regarding the lack of available information about lean mining lifecycle, this literature reviewing has focused on the manufacturing sector to obtain data through peer reviewed papers and technical reports. A combination of the following keywords have been used to find the most relevant data: lean manufacturing, lean tools, lean mining, 5S, kaïzen, VSM, TPM, SMED, LIC, continuous improvement, lifecycle, road-map, and lean stages. The search has been conducted through following scientific databases: Compendex and INSPEC, IEEE Xplore, Scopus, ProQuest, ScienceDirect, and Google Scholar. The final results will be contextualized from the manufacturing sector to the mining environment. This will allow coming up with a possible framework for implementation of lean in mining companies and addressing the first objective of this study.

### 2.3.2 Semi-directed interview with Canadian experts

There are three different ways for conducting a qualitative interview. The interview could be instructed, semi-directed or narrative (Stuckey, 2013). Among these methods, the semi-directed structure of the interview makes it possible to ask more open ended questions. Asking more general and less specified questions from Canadian experts (i.e. academics and practitioners with prior knowledge and experience regarding underground mining, lean and OHS) will let them share their opinions and concerns about the possible impacts of OHS and productivity on main lean tools. Moreover, it might reveal which lean tools are more adaptable within this mining environment at different stages of lean implementation from experts' point of view. Considering that not much experience about using lean tools at the selected mine exist, using a semi-directed interview fits better to gain the required data for answering this thesis research question. Semi-directed interview gives more flexibility over fully directed interview in form of asking questions and can generate comparable qualitative information (Bernard, 2011). The collection of data through semi-directed interview from experts will document the expectations, barriers, and the perceived difficulties, challenges and successes in lean implementation. It will also document the related work experience of the experts, their training and their knowledge of the working conditions and work management arrangements about lean mining. An important aim of conducting semi-directed interview is to investigate the links between lean tools and the dependent variables based on the experts' points of view. A modified questionnaire will be used for conducting the interview. This questionnaire is based on a semi-directed interview in a Ph.D. dissertation about the barriers and challenges for implementation of lean concepts in manufacturing and health care sectors (Bengt, 2013). This questionnaire was used for that specific study. Therefore, it might be in need of more investigations to become fully validated. To the best of this author's knowledge, no other fully validated semi-structured questionnaire could be found in the literature which could lead to an answer to the research questions and objectives of this thesis. For this purpose, a modified version of this questionnaire (which has been modified according to the thesis objectives and research question) will be used for conducting the interviews (Appendix V). Table 2.5 shows a brief description about the data gathering method that will be used for each variable and the purpose of using each method.

Table 2.5 Data gathering methods for dependent and independent variables

| *Type* | *Indicator(s)* | *Data gathering method* | *purposes* |
|---|---|---|---|
| Independent Variable (lean tools) | VSM / 5S / Kaïzen / TPM / SMED / LIC | Literature reviewing | Propose a road-map for usage of each tool in a certain stage of lean implementation. |
| | | Semi-directed interview | Finding out about proper lean tools to be used. |
| Dependent Variable (OHS) | Struck by an object / Body reaction | Literature reviewing | Finding out about the current link between using lean tools and OHS in the mine. |
| | | Semi-directed interview | Finding out about the possible challenges after implementation of lean. |
| Dependent Variable (Economy) | Advance rate per day | Literature reviewing | Finding out about the current link between using lean tools and productivity in mine. |
| | | Semi-directed interview | Finding out about the possible challenges after implementation of lean. |

## 2.4 Methods for analyzing data

The next step after collecting all the required data is to analyze and interpret them. This will help to have a better understanding about obtained data and realize how these data can actually lead to an answer to the research question. Patton (2002) defines the process of analyzing qualitative data as followed: "*reducing the volume of raw information, sifting trivia from significance, identifying significant patterns, and constructing a framework for communicating the essence of what the data reveal*" (Patton, p. 431).

As Bryman (2002) mentioned, there is no single way or best way to analyze qualitative data. According to Flick (2013), there are three approaches for analyzing qualitative data. The first approach focuses on establishing subjective experiences. Data usually are gathered from interviews or written documents and questionnaires. The second approach's aim is to describe a situation. Field observation is an example for the source of data to be analyzed in this approach. The last approach is a combination of the previous approaches and mostly is being used for analyzing interactions between different social phenomena. Considering that in this study data are obtained through semi-directed interviews, the first approach fits better for analyzing obtained data. An effective way for ordering information through text and interviews is to use relevant computer software. Although using computer software could be helpful for analyzing qualitative data; however, it should be mentioned that these software do not actually analyze qualitative data. Instead, they provide a platform that eases the process of analyzing qualitative data (Flick, 2013).

In this study, data will be processed in three main steps. The first and third steps will be done manually and computer software will be used for the second step.  Firstly, all the information gained from the interview will be manually converted to text. Secondly, by using an Excel spreadsheet, all the important keywords (relevant to the research question) within the text will be categorized and classified (i.e. productivity, productive, performance, safety, injury, health, OHS, prevention, positive, impact, link, more studies, increase, decrease, improve, improvement, avoid, effective, efficient, reduction, reduce, lean tools, profitable, cost). Using Excel spreadsheet could be helpful for sorting those patterns which are the same to find meaningful behaviour in them (Berg, 2001). Finally, the identified patterns will be studied manually and will be compared with previous literature so a conclusion could be made to answer the research question. Selection of Excel spreadsheet is made because of its capability in recording data and having a user friendly interface which makes it easier to gain required patterns from input data and also the limited number of obtained statistical data in this research. To ensure the confidentiality while treating the data, an offline version of the Excel will be used at all the time. This will guarantee that obtained information from the experts will not be stored in a cloud or an unknown storage via this software, thus protecting data from a confidentiality breach. Table 2.6 shows the procedure for data analysis in this thesis.

Table 2.6 Data analysis procedure of this study

| *Steps* | *Type* | *Descriptions* |
|---|---|---|
| 1 | Manual processing | - Converting information from interview into text. |
| 2 | Computer software processing (using Excel spreadsheet) | - Sorting and categorizing the important keywords within the text (e.g. lean mining, OHS, productivity, lean tools).<br>- Identifying patterns among the sorted data and establishing links between dependent and independent variables. |
| 3 | Manual processing | - Comparing identified patterns and links with previous studies to reach to a conclusion |

# CHAPTER 3

# LEAN MINING, PRODUCTIVITY AND OCCUPATIONAL HEALTH AND SAFETY: AN EXPERT-ELICITATION STUDY

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In this chapter, the results of this thesis will be presented in the form of a peer-reviewed journal paper. The main aim of this chapter is to address the second objective of this thesis and consequently provide answer for the research question. This paper includes a concise introduction and literature review about lean mining (section 3.1 & 3.2), methodology of this thesis (section 3.3) following by presenting the obtained results from the experts (section 3.4) and a final discussion and conclusion (section 3.5 & 3.6).

## 3.1 Abstract

The implementation of lean tools in the Canadian mining industry is still in its beginnings. To the best of our knowledge, published information and articles on this subject is scarce. Consequently, the impacts of using lean tools on productivity and workers' health and safety in this field are still unclear and need more investigation to better integrate the technical aspects of lean with OHS. Therefore, this study aims to provide insights about lean mining in Canada. The objective of this paper is to propose a preliminary road-map for lean implementation considering OHS concerns in Canadian underground gold-mining. To meet this objective, a set of lean tools (i.e. VSM, 5S, Kaïzen, TPM, SMED and LIC) as independent variable, and OHS indicators (i.e. "struck by an object" and "body reaction" risks) and an economic indicator (i.e. daily advance rate) as dependent variable were selected. An expert-elicitation study was conducted recruiting 7 experts from academia and practitioners active in the mining field. Results show that the majority of experts agreed on a possible positive impact on a mine's daily advance rate after implementing 5S and TPM, and a reduction of the risk rate of "struck by object" among workers by implementing Kaïzen.

**Keywords**: lean mining, lean tools, occupational health and safety, expert elicitation, preliminary road-map, underground gold mine.

## 3.2 Introduction

Lean manufacturing (originating in the Toyota Motor Company) derives from the adoption of Ford's production system by Toyota's management team, initially known as Toyota Production System (TPS) (Ohno, 1988). Womack *et al*., (1990) discovered shortcomings in the Ford system especially with regards to the interaction with employees not involving them in the production process. The Toyota management team improved the TPS and introduced the lean manufacturing system to the world, a production system that helped them improve their productivity and increase their profits through systematic process waste removal (Shingo *et al*., 1989; Womack *et al*., 1990). In the past three decades, many companies from different sectors have tried to implement lean management into their production platforms after witnessing the major success of lean at Toyota (Flynn *et al*., 2015; Bhamu *et al*., 2014). To this effect, companies around the world and from various industrial sectors started using different tools to implement lean and eliminate or reduce seven stages of waste in their daily activities (Sternberg *et al*., 2012). Bhamu *et al*., (2014) and Hodge *et al*., (2011) summarize that tools such as five S (5S), Value Stream Mapping (VSM), Kaïzen, Single-Minute Exchange of Die (SMED) and Total Productive Maintenance (TPM) were mostly used and cited in the literature to implement lean in the manufacturing sector.

## 3.3 Literature review: Lean mining

There are plenty of publications on the results of lean tools in the manufacturing sector (Flynn *et al*., 2015). However, for the mining industry, there is little information and very few studies about lean implementation (Lööw, 2018; Hasle, 2014). Sanchez *et al*., (2004) mention that it might be possible to implement the principles of lean equally in every industry. On the other hand, Hattingh *et al*., (2010) points out the different nature of the mining environment compared to the manufacturing sector and questions the possibility of successfully integrating lean tools in mining with the same approach as has been used in the manufacturing sector. In addition, Khaba *et al*., (2018) points out that the level of lean awareness amongst miners could vary from one mine to another. Factors such as variability and uncertainty are known barriers in mining that can hinder the implementation of lean in this sector (Nadeau *et al*., 2015; Flynn *et al*., 2015). Available literature addresses mainly the improvements in productivity once lean tools have been used (Castillo *et al*., 2014; Ade *et al*., 2012; Dunstan *et al*., 2006). Little or no information exists in the literature about the impacts of using lean tools on miner OHS conditions (Nadeau *et al*., 2015; Ade *et al*., 2012). Table 3.1 summarizes the available studies that examine the use of lean tools in the mining sector. These studies can be categorized as follows based on the implemented lean tools:

- *Lean Information Center (LIC):* In conjunction with 5S, using LIC resulted in early stage performance improvement in an aluminum mine, cycle time reduction in a bauxite mine and cycle time enhancement in an underground copper mine (Dunstan *et al*., 2006).

- *5S*: Process time reduction in a coal mine (Liu, 2013) and incident rate reduction in an aluminum mine (Dunstan *et al*., 2006).

- *VSM*: Productivity improvement in a fluorspar mine, enhancement of process value-added and possible improvement in the miners' overall health in an amethyst mine (Flamarion Klippel *et al*., 2008) and production rate increase in a coal mine (Ade, 2012) and possible cycle time reduction in a diamond mine (Maunzagona *et al*., 2017).

- *Kaïzen*: In conjunction with other tools such as VSM and 5S, using Kaïzen resulted in project performance and productivity enhancement in a copper mine (Castillo *et al*., 2014) and possible improvements in the miners' health and safety conditions (Vaněk *et al*., 2015).
- *TPM*: Repair time reduction in a copper mine (Chlebus *et al*., 2015).

It is important to mention that there are certain differences in the legislative, environmental and geological conditions in each country specified in Table 3.1. Therefore, comparing these results may not be as accurate without considering these differences. Moreover, there are some drawbacks and limitations in the implementation of lean mining (Hines *et al*., 2018). There is some confusion about the actual meaning of lean in the literature (Stone, 2012). Bhamu *et al*., (2014) found over 33 different definitions of lean manufacturing while reviewing a wide range of literature. Among these definitions, one of the most cited in the literature is presented by Shah & Ward (2007). Consequently, this paper has chosen it as its definition of lean: *"An integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability"* (Shah & Ward, 2007, p.791). Stahl *et al*., (2015) argued that some companies are ignoring the actual concept of lean in a social sense and are using lean tools only for waste removal purposes and improving their productivity. This approach can lead to limited and unsustainable results (Mazzocato *et al*., 2010; Repenning *et al*., 2001).

Table 3.1 Available case studies on the topic of implementing lean tools in the mining sector

| *Country* | *Type of mine* | *Tool(s)* | *Effect(s) on economic aspect* | *Effect(s) on OHS aspect* | *Author(s)* |
|---|---|---|---|---|---|
| Australia | Aluminum | LIC, 5S, TPM | Performance improvement (in early stage of lean implementation) | 57% decrease in the rate of incidents among miners | Dunstan *et al*., (2006) |
| Australia | Bauxite | LIC & 5S | Cycle time reduction | - | Dunstan *et al*., (2006) |
| Australia | Underground copper mine | LIC | 56% enhancement in the cycle time | - | Dunstan *et al*., (2006) |

Table 3.1 Available case studies on the topic of implementing lean tools in the mining sector (Continued)

| *Country* | *Type of mine* | *Tool(s)* | *Effect(s) on economic aspect* | *Effect(s) on OHS aspect* | *Author(s)* |
|---|---|---|---|---|---|
| Brazil | Fluorspar | VSM | 43.6% raise in productivity | - | Flamarion *et al*., (2008) |
| Brazil | Amethyst | VSM | 16.6% improvement in the process added-value time | Possible enhancement in the miners' health due to reduction of dust | Flamarion *et al*., (2008) |
| Chile | Copper | VSM, 5S, Kaïzen | Enhancement in project performance and productivity | - | Castillo *et al*., (2014) |
| China | Coal | 5S | 16.5% reduction in processing time | - | Liu, (2013) |
| Czech Republic | Coal | Kaïzen | - | Possible enhancement in the miners' safety and health conditions | Vaněk *et al*., (2015) |
| India | Coal | VSM | 16.8% increase in production rate | Possible reduction in the required effort to move materials by miner after installation of man-rider system | Ade *et al*., (2012) |
| Poland | Copper | 5S, TPM | Decrease in average repair time | - | Chlebus *et al*., (2015) |
| South Africa | Diamond | VSM | Cycle time reduction | - | Maunzagona *et al*., (2017) |

Moreover, improper implementation of lean, lack of experience in using lean tools, and lack of commitment from management can lead to negative outcomes while using lean tools (Ferreira *et al*., 2015; Dal Forno *et al*., 2014). The employees' overall safety and health can be negatively affected by improper implementation of lean (Adler, 1999). Increasing the accident and injury rate in the workplace (De Treville *et al*., 2006), deteriorating the level of health and increasing the stress level of employees (Brenner *et al*., 2004), and adding onto the workload and intensity of the employees' job (Brännmark *et al*., 2012; Westgaard et al., 2011) have all been reported as negative results of improper usage of lean tools. On the other hand, lean can have positive impacts on OHS by involving workers on the job, enhancing the workers' training, and proposing improved tasks for them (Nadeau *et al*., 2015). However, to the best of our knowledge, the available relevant results about these possible effects in mining are still insufficient, which makes it difficult to compare one company to another (Dunstan *et al*., 2006; Flamarion Klippel *et al*., 2008;  Ade *et al*., 2012; Vaněk *et al*., 2015). So far, to the best of our knowledge and based on the limited published literature in mining, the technical aspects of lean have not yet been integrated with the OHS aspects. To fill this gap, the objective of this paper is to develop a preliminary road-map to help integrate lean tools into mining industries considering their impacts on the overall health and safety of miners.

## 3.4 Methodology

### 3.4.1 Research method

As previously mentioned, information about the implementation of lean tools in mining regarding OHS issues is scarce in the literature (Nadeau *et al*., 2015). Therefore, to gain in-depth knowledge about this subject for this paper, a qualitative research approach was followed (Creswell, 2013; Fortin, 2010). An expert elicitation study using semi-directed interviews was undertaken to discover any possible links between the integration of lean tools and the economical and OHS aspects of the mining sector. The focus of the study is on an underground gold mine, at the extraction level and in the early stages of lean implementation in Canada. Therefore, Canadian experts who have previous work experience in the same field were considered as potential participants for interviews and data collection.

### 3.4.2 Identifying variables: dependent and independent variables

The first step in designing the expert elicitation method is to identify the variables involved. A set of lean tools that have been frequently used in the mining field were categorized as the independent variable (Chlebus *et al*., 2015; Nadeau *et al*., 2015; Castillo *et al*., 2014; Liu, 2013; Ade, 2012; Dunstan *et al*., 2006). VSM, 5S, Kaïzen, TPM and LIC are, in the literature, a pre-selected set of tools to be studied as an independent variable. Moreover, based on a proposal by Nemati *et al*. (2019) as to the possibility of using SMED in an underground mining environment, this tool was added to the list of lean tools as an independent variable as well. To investigate the relationships between these tools and economic and OHS indicators in the mining environment, dependent variables needed to be defined as well. According to reports published by the *Commission des Normes, de l'Équité, de la Santé et de la Sécurité du Travail* (CNESST) and the *Ministère de l'Énergie et des Ressources Naturelles* (MERN), "struck by an object" and "body reaction" were two common OHS issues in underground gold mines in Québec (MERN, 2012; CNESST, 2011). Therefore, these two indicators were selected as OHS-dependent variables. As for an economic indicator, increasing the rate of production is an important factor to consider in the mining field (Pareja, 2000). Taking into account the geological and environmental conditions in Canadian underground gold mines, productivity is tied with the daily advance rate for extracting ore (Pareja, 2000). Consequently, the advance rate per day was chosen as the economic dependent variable.

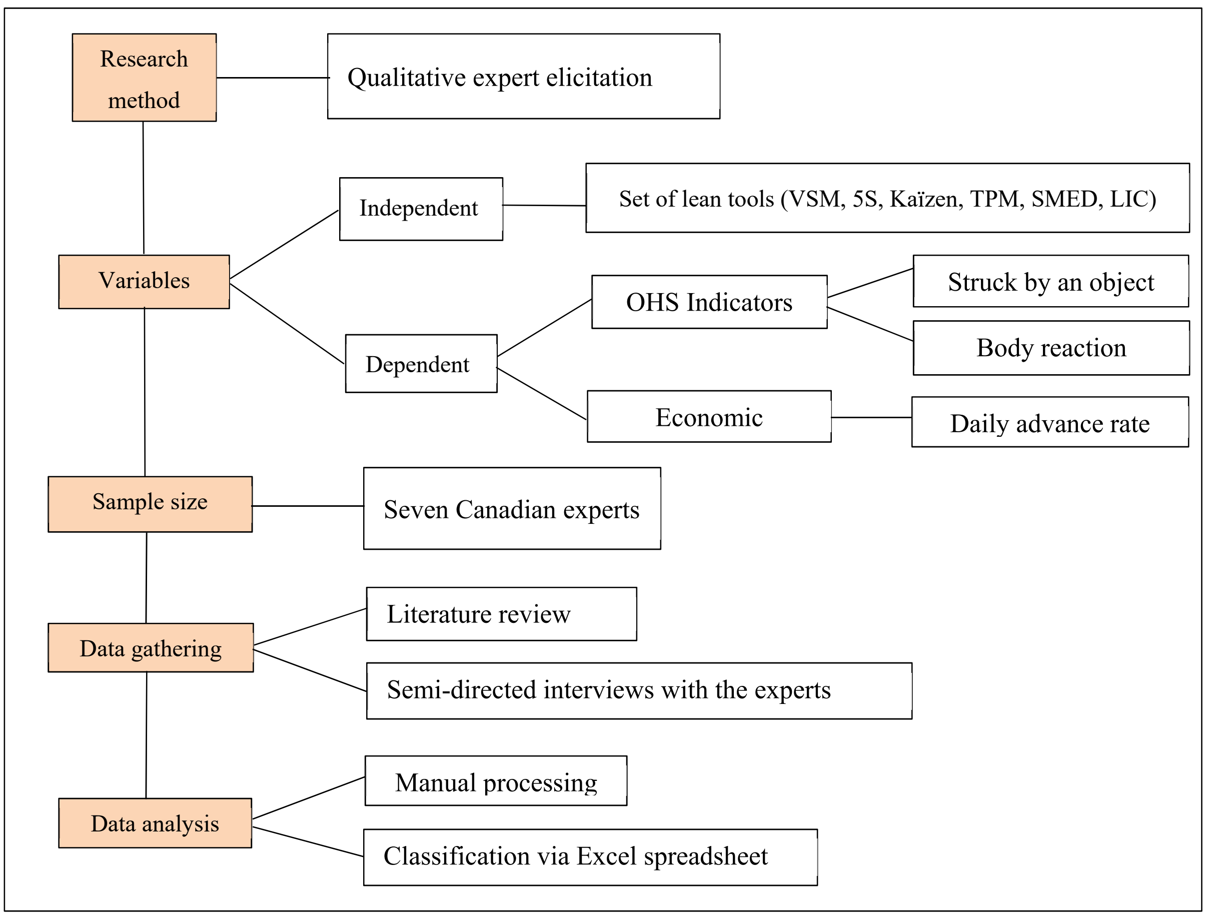


Figure 3.1 Methodology diagram of this research

### 3.4.3 Data gathering and analysis method

Holding a semi-directed interview with Canadian experts was deemed useful to record the expectations and perceived difficulties, challenges and successes in implementing lean tools from the experts' point of view. In a first step, the authors of this paper met with the Ethics Committee of École de technologie supérieure (ÉTS) and received their approval in September 2018. This compliance was followed by the approval of the Ethics Committee of Université du Québec en Abitibi-Témiscamingue (UQAT). Subsequently, a total of 7 Canadian experts were interviewed for this project (a suitable sample size). These experts were chosen amongst active academia and practitioners in the mining field. Obtained data from the interviews were converted to text and then categorized using an Excel spreadsheet. By using this software, the important keywords within the text (i.e. productivity, productive, performance, safety, injury, health, OHS, prevention, positive, impact, link, more studies, increase, decrease, improve, improvement, avoid, effective, efficient, reduction, reduce, lean tools, profitable, cost) were categorized and sorted and their patterns were compared with each other to find meaningful behaviours (Berg, 2001). The output results were interpreted in the last step, that is, the identified patterns were studied and the results were compared with the literature to draw a conclusion. Figure 3.1 shows the different steps of the methodology of this research.

## 3.5 Results

As mentioned above, a semi-directed questionnaire was distributed to the experts. The experts' average age was 55 (±13). They had an average of 20 (±15) years of experience in the mining field. 43% of them are active academia and the other 57% are practitioners working in the mining industry. In the semi-directed questionnaire, the experts were all asked to express their opinion on the current level of lean implementation in Canadian underground gold mines. The majority agreed that this level is low. According to them, lean mining is hardly spoken of among workers in Canadian mines. Moreover, according to the experts in our sample, the use of lean by management teams in the mining industry is limited to improving productivity. A good 72% of the experts commented that implementing lean mining will increase the efficiency, improve the productivity and eliminate wastes within the underground mining environment. According to 88% of them, resistance to change among workers, managers and stakeholders could be the main existing barrier to the successful implementation of lean. Experts were asked to define lean from their own perspectives. Most of them (72%) described lean as a management approach for reducing costs, minimizing loss of time and optimizing production. Regarding lean-related training, 88% of the experts stated that they did not have any prior formal training. Furthermore, the majority did not know or were not sure what types of lean tools are being used for the implementation of lean in mining. The experts were also asked about their opinions regarding possible connections between the set of lean tools and each OHS and economic indicator. A summary of these results can be seen in Table 3.2.

Table 3.2 Results summary of experts' opinions regarding the relationship between lean tools and OHS and economic indicators

| Dependant variables → | | OHS Indicators | | Economic indicator |
|---|---|---|---|---|
| ↓ Independent variables | | Struck by an object | Body reaction | Daily advance rate |
| A set of lean tools | VSM | - 57% did not know if there was a link.<br>- It depends on the mine | - 71% did not know if there was a link. | - 71% did not know if there was a link.<br>- It can increase the paper work. |
| | 5S | - 57% did not know if there was a link.<br>- It might be difficult to sort the mining supplies. | - 43% did not think there was a link. | - 43% believed that there is a link.<br>- It can increase productivity. |
| | Kaïzen | - 57% agreed that there is a link.<br>- Elimination of bottleneck<br>- Better understanding of tasks and responsibilities. | - 43% did not know if there was a link. | - 43% did not know if there was a link.<br>- 43% believed that there could be a positive link. |
| | TPM | - 43% did not know if there was a link. | - 43% did not know if there was a link.<br>- 43% believed that there is no link. | - 57% agreed that there is a link.<br>- It can increase the daily advance rate. |

Table 3.2 Results summary of experts' opinions regarding the relationship between lean tools and OHS and economic indicators (Continued)

| Dependant variables → | | OHS Indicators | | Economic indicator |
|---|---|---|---|---|
| ↓ Independent variables | | Struck by an object | Body reaction | Daily advance rate |
| A set of lean tools | SMED | - 57% did not know if there was a link. | - 86% did not know if there was a link. | - 57% did not know if there was a link. |
| | LIC | - 57% did not know if there is a link. | - 57% did not know if there is a link. | - 43% did not know if there is a link. |

### 3.5.1 VSM

For VSM, the majority of the experts did not think or were not sure whether there is a link between this lean tool and “struck by object” risks (57%), “body reaction” risks (71%) and “daily advance rate” (71%). This could indicate that more studies are required to assess the outcomes of using VSM on the OHS and productivity indicators for an underground mining environment.

### 3.5.2 Five S

As for 5S, 57% of the experts did not know if there is a connection between 5S and “struck by object” risks and 43% did not think there was a possible link between 5S and “body reaction” risks. On the other hand, the majority of the experts (43%) believe there is a connection between the “daily advance rate” and 5S. Improving productivity is a positive effect of using 5S in the mining industry from these experts’ point of view. This means that implementing 5S elements in the workplace should improve the daily advance rate.

### 3.5.3 Kaïzen

57% of the experts agreed that a positive link exists between Kaïzen and “struck by object” risks. Elimination of bottlenecks, better understanding of the tasks and responsibilities are a few of the reasons given by the experts regarding the positive effects of implementing Kaïzen. This indicates that by having an optimal process and implementing continuous improvement practices in the workplace, the “struck by object” risks should decrease. For the other OHS indicator, the majority of the experts (43%) did not know if there is any link between Kaïzen and “body reaction” risks. Eventually, less than half of the experts (43%) responded that they do not know whether there is a link between this lean tool and the “daily advance rate” for Canadian underground gold mines. That being said, the same number of experts (43%) commented that there might be a positive link. These experts agreed that Kaïzen can improve productivity and enhance efficiency through continuous improvement practices.

### 3.5.4 TPM

For this tool, the majority of the experts did not know if a link could be made between TPM and “struck by object” risks (43%). The results are divided in two groups as for “body reaction” risks. A first group of 43% did not know about a link while the other 43% mentioned that there is no link to be made between these two variables. The majority of the experts (57%) mentioned that there could be a link between TPM and productivity. According to these experts, increasing the “daily advance rate” and obtaining an uninterrupted production pace can be achieved by properly implementing TPM. This indicates that performing a regular maintenance according to the TPM guideline should improve the productivity of the underground mine.

### 3.5.5 SMED

Similar to VSM, the majority of the experts did not know if a connection could be made between SMED and “struck by object” risks (57%), “body reaction” risks (86%) and “daily advance rate” (57%). This could mean that the obtained results are inconclusive and that more studies are needed to investigate the outcome of using SMED on OHS and productivity indicators in the mining environment more thoroughly.

### 3.5.6 LIC

Again, similar to VSM and SMED, the majority of the experts did not know if there is a link between LIC and “struck by object” risks (57%), “body reaction” risks (57%) and the daily advance rate (43%). This could mean that an assessment of the outcomes of implementing SMED on OHS and productivity indicators in the mining environment requires more study.

By combining all the statistical results related to each variable in this study, Fig. 2-4 were produced. These figures present the experts’ overall opinions about the possible connection and the predicted impacts of implementing a set of lean tools on “struck by object” risks (Fig. 3.2), “body reaction” risks (Fig. 3.3) and the daily advance rate in the Canadian underground gold-mining sector (Fig. 3.4).

The experts’ opinions about the current level of OHS in Canadian underground gold mining sector were recorded as well. Most of them believed that at the moment, the level of OHS in mining is satisfactory. They commented that from their point of view, OHS has been rapidly improving in the Canadian mining industry. It is worth mentioning that according to the mining association of Canada, the rate of worker accidents and injuries in the mining field has been decreasing in Canada over the past few years (Marshal, 2016). The experts’ opinions about the existence of a health-related issue in connection to lean implementation is divided into two groups. One group of 43% of the experts commented that there could be psychological health concerns arising from increased stress among workers linked to the changes imposed by lean implementation. According to them, productivity and health do not always go together. On the other hand, the other group (also 43%) did not see the possibility of any health-related problems arising from implementing lean. By combining all the answers from the experts regarding the possible connection between implementing the set of lean tools and the two OHS indicators, it can be seen that around 54% of the experts’ answers were that they did not know it there is a link between the implementation of lean and these two OHS indicators in mining (Fig. 3.5.a).

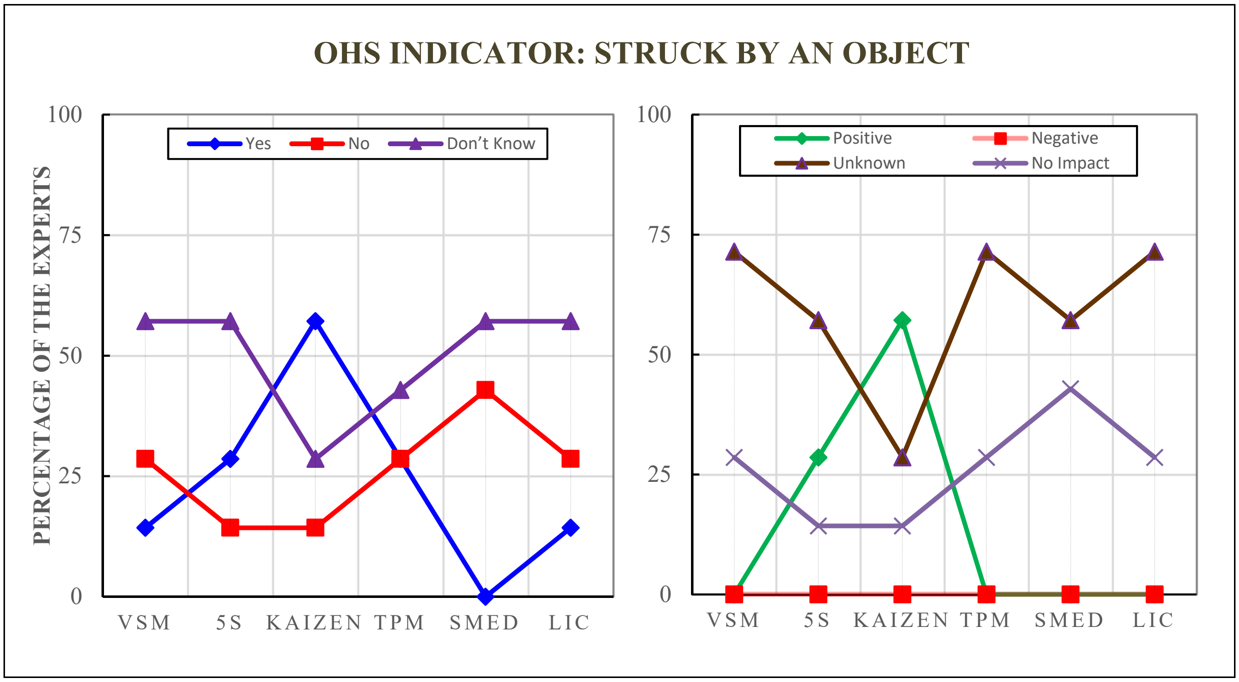


Figure 3.2 Experts' opinions about the possible connections (left) and the predicted impacts (right) of implementing a set of lean tools on "struck by an object" among workers in the Canadian underground gold-mining sector

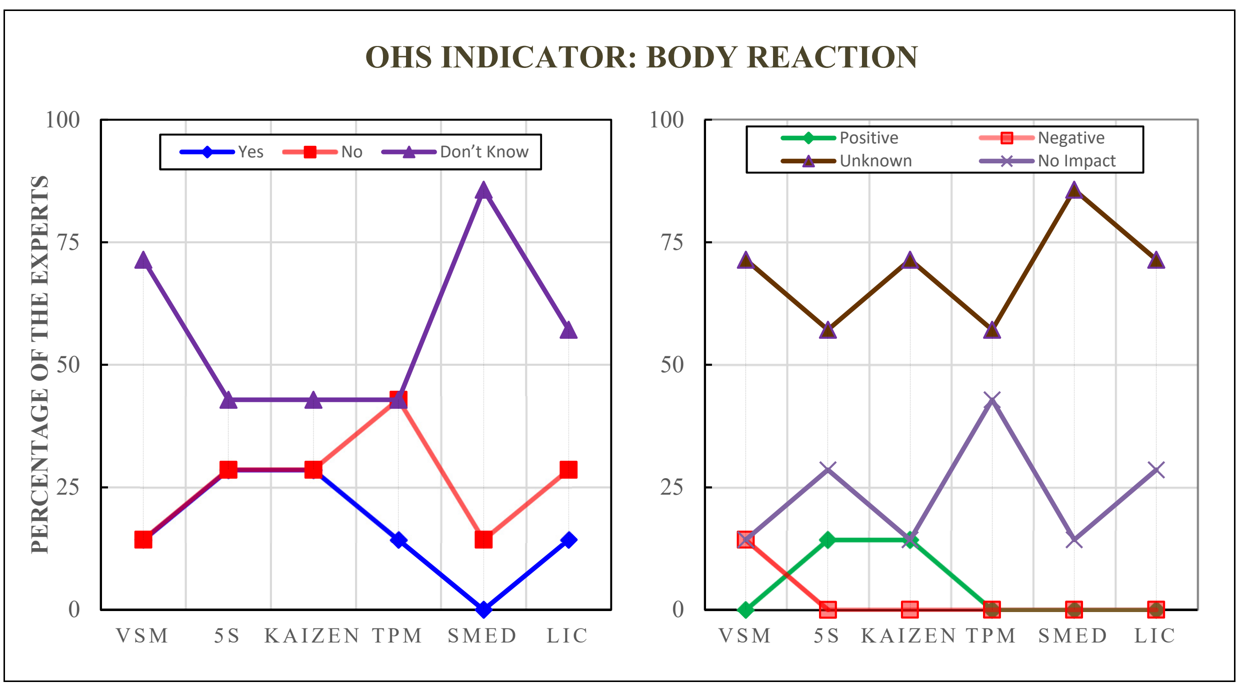


Figure 3.3 Experts' opinions about the possible connections (left) and the predicted impacts (right) of implementing a set of lean tools on "body reaction" among workers in the Canadian underground gold-mining sector

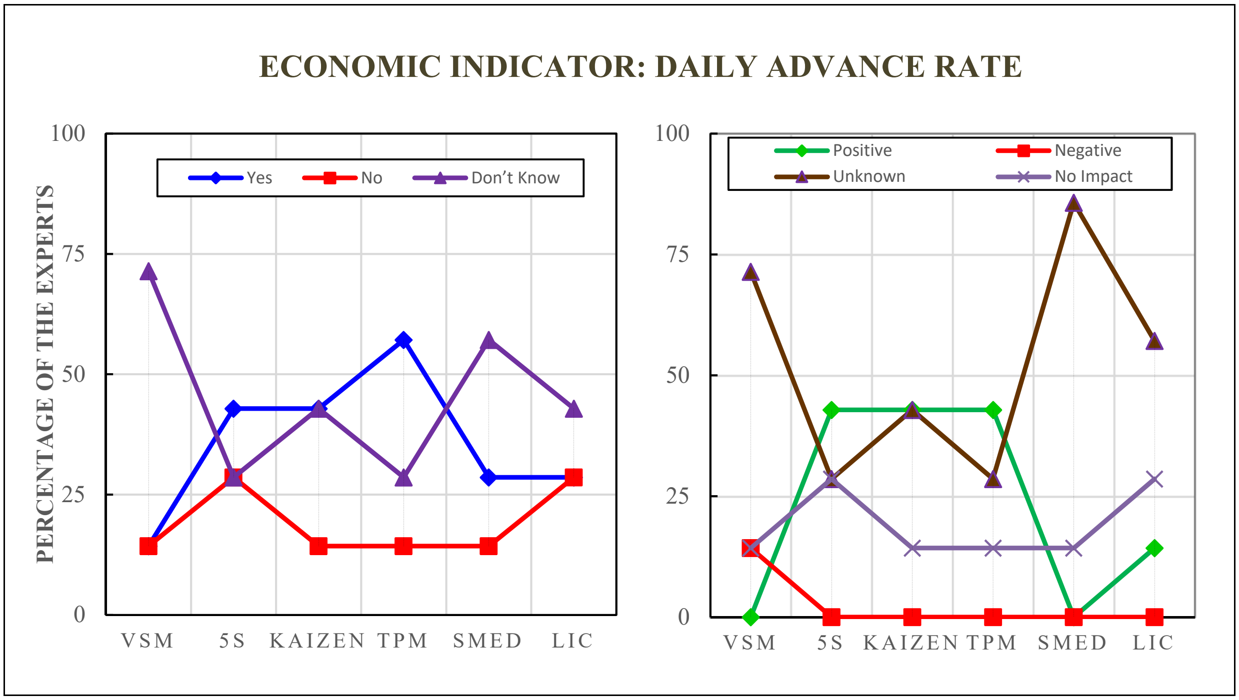


Figure 3.4 Experts' opinions about the possible connections (left) and the predicted impacts (right) of implementing a set of lean tools on "daily advance rate" in the Canadian underground gold-mining sector

From an economic standpoint, all of the experts agreed that the current economic situation of Canadian underground gold mines is positive and also, that it is improving. Based on the literature, Canada is one of the biggest worldwide producers of minerals (and a major producer of key materials such as gold ores) (Brendan, 2016; Rupert & Columbia, 2013). On the other hand, the experts' opinions on a relationship between the economic indicator and lean implementation is again divided into two groups. The first group, 43% of the experts, believed that lean could be costly to implement in the beginning. Costs associated with implementation such as training and supervision are a few of the examples given by these experts. On the other hand, the other group of experts (43%) did not see any economic-related problem connected to lean implementation. By combining all the answers from the experts regarding the relationship between implementing the selected set of lean tools and the economic indicator, it can be seen that about 45% of the experts' answers were that they did not know whether there is a connection between implementing lean and the economic indicator for mining (Fig. 3.5.b).

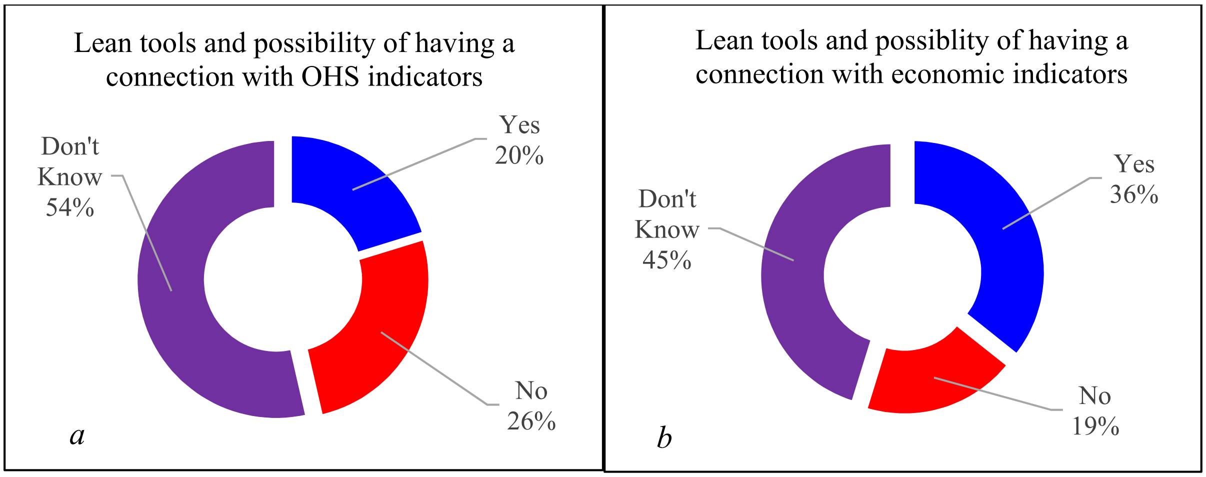


Figure 3.5 Experts' overall opinions regarding the existence of a possible connection between the set of lean tools, the two OHS indicators and the economic indicator in underground gold-mining environment (respectively a, b).

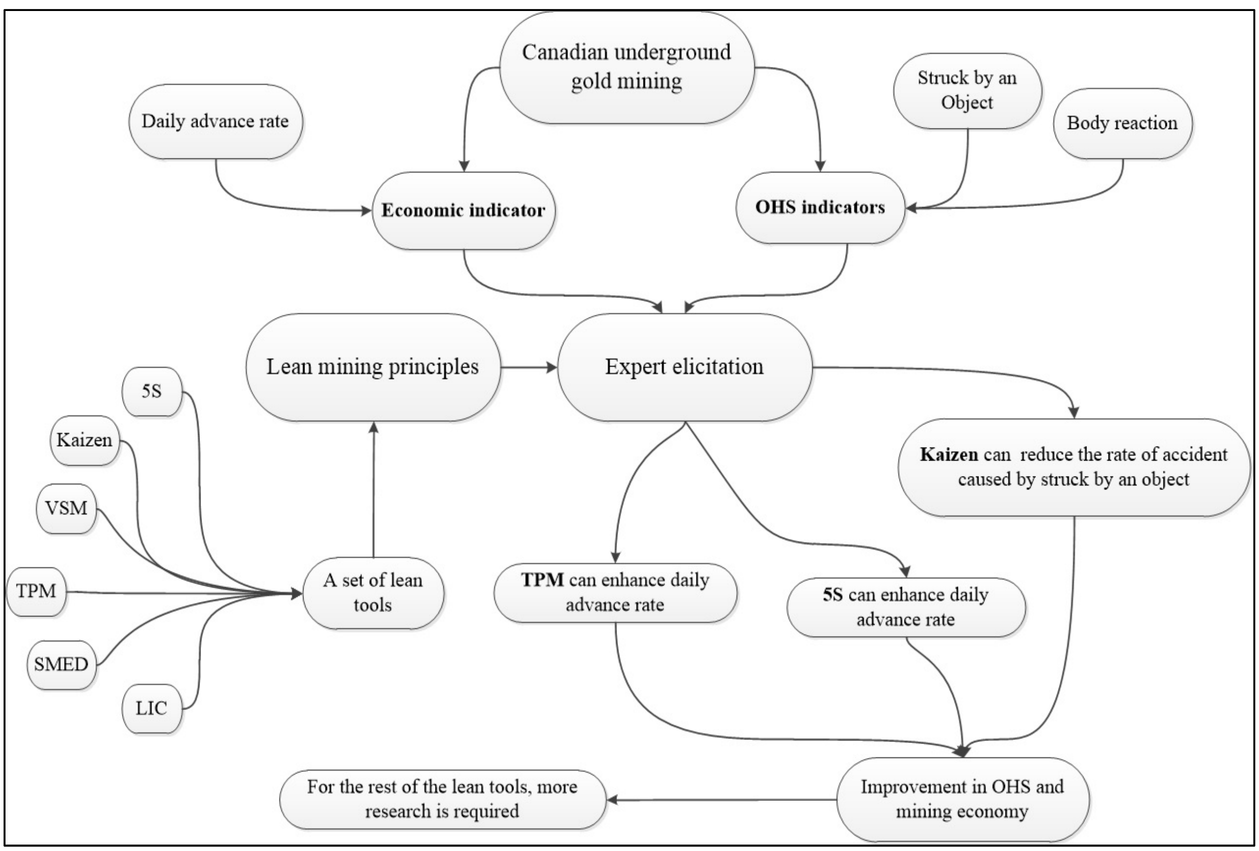


Figure 3.6 A preliminary road-map (created via mind-mapping) to implement lean mining, based on the findings of this study

An overview of the obtained results of this research is presented in Fig. 3.6. This figure shows the final results of this study and generates a preliminary road-map to help implement lean mining and address the objective of this research.

## 3.6 Discussion

### 3.6.1 Limitations and biases

Initially, a total of 10 experts were recruited. Considering that only 7 completed the questionnaire, the results of this research are limited to gold mining. Moreover, having such a small sample size prevents a generalization of the final results of this expert-elicitation study (Yin, 2013). On the other hand, for a study with little or no earlier background information, the qualitative expert-elicitation method provides the opportunity to gain some background information about the new topic (Baxter *et al*., 2008). Holding a semi-directed interview with Canadian experts can give more flexibility over the other types of interviews, for instance, asking more general and open-ended questions and generating comparable qualitative information (Bernard, 2011). This method is especially useful when not much experience about the studied subject has been documented a condition that applies to this study as well.

One of the possible biases of this research could be due to each expert's mindset about lean. Each expert might have their own perspective about lean, which could differ from that of the other experts. As mentioned in the results section, the majority of the experts described lean as an effective way to minimize loss of time, reduce costs and optimize production. This indicates that most of them see lean as a waste management tool to improve efficiency. This is in accordance with what was established as the definition of lean in this paper (Shah & Ward, 2007). Another bias of this study is that almost none of the experts had any previous formal lean-related training. Some experts obtained their information about lean through readings and waste-elimination practices used by their mining companies, which could be considered as a form of training. However, this could have an impact on the presented results.

### 3.6.2 Literature comparison

By comparing the findings of this study (Table 3.2) with the literature (Table 3.1) it can be noticed that these findings are consistent with what has been found by the above-mentioned authors using different research protocols. In the literature, 5S and TPM were reported to be effective tools for production enhancement in coal, aluminum and copper mining (Chlebus *et al*., 2015; Liu, 2013; Dunstan *et al*., 2006). The same results for these tools were obtained in this study for underground gold mining. As for Kaïzen, a possible improvement in miners' safety and health conditions was reported by Vaněk *et al*. (2015) in coal mining. Decreasing the rate of the risk of being struck by an object after implementing Kaïzen was one of this research's findings.

### 3.6.3 Future studies

This study was an attempt to make an initial foray for further studies by creating a preliminary road-map to help implement lean in the mining sector regarding workers' health and safety. Future studies can focus on more field work observations and case studies to investigate lean mining more in depth. Knowing that results of this study were obtained for the underground gold-mining sector, other mining sectors should be involved in future studies as well, to create a more comprehensive and conclusive road-map regarding the connection between lean mining, OHS and productivity in Canadian mines.

One of the main objectives of this study was to investigate the connection between implementing lean and OHS and productivity in the mining environment. The final results showed that some lean tools can be effective in enhancing OHS and mining productivity. However, the impact of lean mining as a whole (implementing a set of lean tools) on OHS and productivity is still unknown (Fig. 3.5). The findings of this study are still inconclusive regarding this matter. This highlights the fact that lean in mining is still emerging in Canada and more research is required to reach more tangible conclusions.

## 3.7 Conclusion

To the best our knowledge, very little information in the literature exists about the impact of lean implementation on mining productivity and OHS. The published information is even rarer regarding the Canadian mining sector. By conducting an expert-elicitation study with 7 Canadian experts, a preliminary road-map was created to show the possible links between lean mining and productivity and workers' safety in Canadian underground gold mining. This map can help to provide more in-depth knowledge about which lean tools would be better to start with for future case studies, to investigate more about the impacts of lean mining on OHS and productivity. Results from both the literature and this study show that tools such as 5S, TPM and Kaïzen may potentially have positive impacts on mining productivity and OHS. This paper showed that using 5S and TPM can increase the daily advance rate and Kaïzen can be useful in reducing the rate of "struck by an object" risks among workers in underground gold mines in Canada. Although this study did not reach a conclusion about the outcome of implementing lean (as a set of tools) on OHS and productivity, it does however pave the way for further research about Canadian lean mining.

**Acknowledgments**

The authors of this paper would like to thank École de technologie supérieure for providing infrastructure, the Natural Sciences and Engineering Research Council (NSERC) for funding and all the experts who volunteered to participate in this research.

# CONCLUSION AND RECOMMENDATIONS

Based on a critical review of literature (see chapter 1), the research question is formulated. The main aim of this thesis (according to the research question) is to find out what kind of lean mining tools can be used and how these tools can be implemented in the Canadian mining industry considering their impact on workers' health and safety conditions. To answer to these questions two objectives are defined.

The first objective is to identify the most suitable lean tools for implementation of lean in the underground mining at extraction level at different stages of lean integration. To meet this objective, a literature review is conducted. This review allows comparing the most common lean tools used in the manufacturing and mining sector. Based on the results of this review, a set of lean tools (i.e. VSM, 5S, Kaïzen, TPM, SMED and LIC) is suggested for the underground mining. Furthermore, a lean lifecycle with four different phases is proposed for implementing this set of lean tools regarding their relevant phases of lean implementation. A proposal to integrate SMED in the underground mining environment is made. Based on this proposal, proper implementation of SMED can potentially enhance productivity and the dust control system (improving OHS as well) in underground mining.

The second objective of this thesis is addressed in the third chapter. This objective is to investigate about the possible links between the proposed lean tools at the early stages of lean implementation and productivity and OHS indicators. Daily advance rate as productivity indicator and struck by an object and body reaction as OHS indicators are chosen to be the dependant variables. These indicators are linked to the Canadian underground gold mining at extraction level. Moreover, the set of lean tools previously proposed (i.e. VSM, 5S, Kaïzen, TPM, SMED and LIC) is considered as the independent variable. To address this objective of this thesis, data collecting is done through an expert elicitation study with 7 Canadian experts active in the mining field. Based on the obtained data from the experts through semi-directed interviews, a preliminary road-map to implement lean mining is created. Moreover, the final results reveal that according to the experts, proper implementation of 5S and TPM can potentially improve the daily advance rate and Kaïzen can be linked to enhancing OHS conditions by reducing the risk of being struck by an object in the mining environment.

To the best of our knowledge, no published information about the outcome of lean mining implementation integrating OHS in Canada exist yet. Therefore, the final results of this study are original and can be helpful for future studies.

# APPENDIX I

## LIST OF PUBLICATIONS

The peer-reviewed article (Chapter 3):

Nemati A. Nadeau S. & Ateme-Nguema B. 2019. « Lean Mining, Productivity and Occupational Health and Safety: An Expert-Elicitation Study ». *The journal of Safety and Health at Work*, submitted (April).

Refereed conference (Appendix II):

Nemati, A. Nadeau, S. Ateme-Nguema, B. Belmont, J. 2019. « Identifying lean tools to improve mining productivity and OHS conditions ». *Accepted (March, 2019) in 13th International Conference on industrial engineering (CIGI QUALITA), 25-28 June, 2019 (École de technologie supérieure (ÉTS), Montréal, Québec, Canada),* In press.

Presented poster in a conference (Appendix III):

Nemati A. Nadeau S. & Ateme-Nguema, B. 2017. « Lean Tools Adaptation into Mining: an Occupational Health and Safety Approach ». *Published (April, 2017) in AQHSST Annual Conference as a poster, 16-18 May 2017 (Victoriaville, Quebec, Canada).*

## APPENDIX II

## CIGI QUALITA CONFERENCE PAPER 2019

# Identifying lean tools to improve mining productivity and OHS conditions: a literature review

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**Abstract**

Elimination of waste and the non-value-added activities are two of the most important goals of lean management. According to the literature, several lean tools exist in the manufacturing sector to achieve this goal. However, the lean tools used in the mining sector are not as well-identified as those used in the manufacturing sector. This paper proposes useful lean tools for the mining industry that can be used at different phases of lean implementation based on the available literature. Moreover, the paper proposes a possible way to implement single-minute exchange of die (SMED) in underground mining to enhance both productivity and the health and safety conditions of miners.

**Keywords**: lean mining; SMED; OHS; lifecycle.

## 1. Introduction

The car manufacturer Toyota was the first company to introduce lean management to the world. They experienced significant economic improvements from the implementation of lean tools (Shingo et al., 1989; Ohno, 1988). Banishing any form of waste was the main idea behind lean management (Womack et al., 1990). There are several publications about other companies in the manufacturing sector that decided to use lean tools after witnessing the success of Toyota (Flynn et al., 2015; Bhamu et al., 2014). However, unlike the manufacturing sector, little or no information in the literature exists about the use of lean tools in other industries (Hasle, 2014), such as mining for instance. Different environmental conditions, uncertainty and variability are some of the barriers that currently hinder the implementation of certain lean tools in mining (Flynn et al., 2015; Nadeau et al., 2015). The few relevant articles that are available in the literature are mostly on how lean tools can enhance productivity and reduce the non-value-added activities in mining (Castillo et al., 2014; Liu, 2013; Ade et al., 2012; Dunstan et al., 2006). Information about the impact on occupational health and safety (OHS) of lean tools on miners, the different phases of lean implementation and its sustainability in mining are scarce in the literature (Nadeau et al., 2015; Castillo et al., 2014; Ade et al., 2012). This paper is intended to fill this gap by identifying lean tools that can potentially be integrated to mining OHS during the early stages of lean implementation (e.g. the extraction phase). Consequently, this paper will focus on identifying the proper stage for implementing each tool based on data obtained from the literature. The novelty of this paper is in proposing a possible way to use SMED in underground mining and investigating the literature (both in manufacturing and mining) to establish which lean tools are suitable for the mining industry. Finally, the framework for adapting lean management to mining is identified and the selected lean tools are assigned to the related stages of that framework both based on the function of each tool and with respect to the miners' OHS conditions.

## 2. Methodology

To fulfill this research objective, a literature search was carried out. The following scientific databases were used to find related papers and technical reports about promising lean tools in the mining and different phases of lean implementation: Compendex and INSPEC, IEEE Xplore, Espace ÉTS, Scopus, ProQuest, ScienceDirect, SpringerLink, Taylor and Francis, and Google Scholar. Different combinations of keywords (using AND/OR/NOT operators) were used to filter the most relevant results, including: Lean mining, Lean and OHS, Lean lifecycle, Value Stream Mapping (VSM), five S (5S), Just In Time (JIT), Kaïzen, SMED, total productive maintenance (TPM), Kanban, Human factor, Ergonomics, Lean tools. Only English-language publications were considered. Conference documents as well as peer reviewed journal articles were taken into account. To keep the results up-to-date, only publications from 2006 to 2018 were retained. Finally, by reviewing the title and abstract of the initial documents, the best matches were chosen and the literature review was completed using the snow ball effect.

## 3. Results

### *3.1. Lean tools*

Bhamu et al., (2014) and Hodge et al., (2011) performed a literature review to identify the most important lean tools in the manufacturing sector. Based on their results, tools such as 5S, VSM, Kaïzen, SMED, and TPM were commonly used to implement lean. In reviewing available case studies about lean mining, tools such as 5S, VSM, lean information center (LIC), Kaïzen, and TPM were found to be used to implement lean (Brodny et al., 2016; Castillo et al., 2014; Liu, 2013; Ade, 2012; Dunstan et al., 2006). Table 1 shows the proposed lean tools to be used in mining.

By comparing the tools common to both manufacturing and mining, one notes that SMED has not yet been used in mining. To the best of our knowledge, no documented result were found in the literature regarding implementing SMED in mining sector. Considering the lack of information about lean tools in mining and the success of using SMED in manufacturing, this section proposes the use of this tool. An important application for SMED in the manufacturing sector is to reduce the setup time of a machine by converting as much internal setup to external setups as possible (Ulutas, 2011). This means for example working on a machine while it is running to eliminate the waste of machine idle time or down time.

Indeed, a good example of a possible way to implement SMED to an added-value underground mining activity is to keep the required tools closer to the workplace to reduce the length of idle time generated during machine part replacement (Ministry of Energy and Natural Resources (Quebec), 2016). To ensure that something useful is being proposed, both OHS and productivity need to be considered. Exposure to dusts and particles produced by drilling is an important issue for miners. Studies show a strong link between exposure to silica and the onset of respiratory diseases and lung cancer among underground miners (Carta et al., 1996; McDonald, 1989). Therefore, a method that can adequately control dust levels is essential to maintaining the miners' health. The most effective and commonly used method is wet drilling (Cecala et al., 2012). In this method, a combination of pressurized air and water is used inside the drill to remove the cuttings from the hole and wash down any dust (drilling is usually done by a jumbo machine with two or more drills). Fig. 1 shows the continuous flow of water through the drill (installed on the jumbo). The water exits from the end of the drill bit thereby removing the cuttings from the drill with high efficiency without causing airborne dust particles.

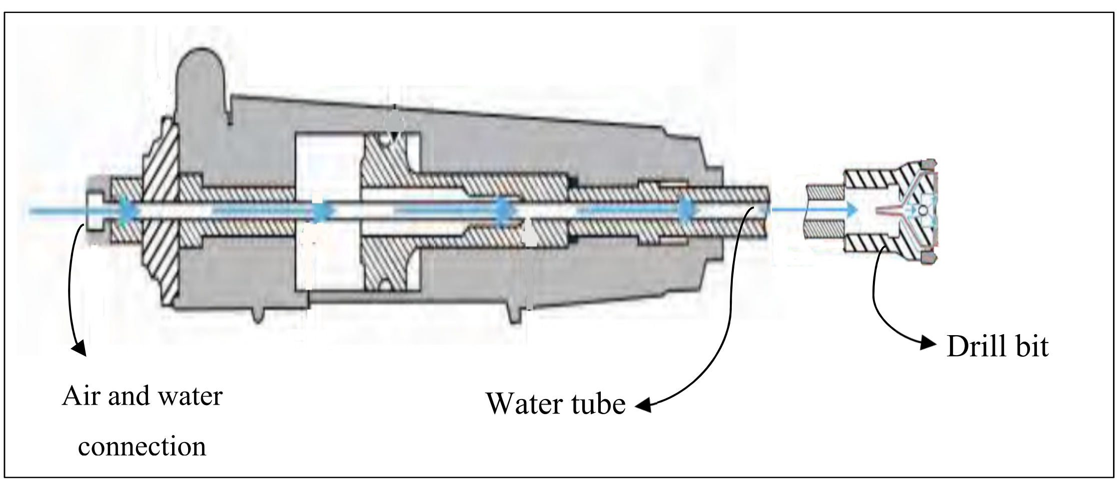


Figure 1 – Wet drilling method (Cecala et al, 2012)

Despite being highly efficient in eliminating dust, this method has a few drawbacks. For instance, drill bit degradation is a common problem that arises due to hydrogen embrittlement (Colinet et al., 2010). The process of changing the drill bit normally needs to be done in a safe dust free environment to avoid damaging the sensitive parts which are connected to the drill (e.g. percussion system, etc). If a blockage or malfunction in the drill's water ejection system occurs, the drill cannot be utilized and needs to be replaced or fixed. All these situations require moving the jumbo drill all the way to a maintenance or safe zone, which means the jumbo will be down, forcing production to stop during the repair. This downtime can be considered as waste (an internal setup activity). By using SMED and loading a spare drill with the jumbo, the process of changing the drill bit can be done on the spot without stopping production (an external setup activity). Furthermore, dust control using water can remain in effect because of on-the-spot drill changing. Eventually, this proposal to use SMED in underground mines can have positive effects on both the economic and OHS conditions of the extraction phase of mining.

Table 1 – Common lean tools in manufacturing and proposed lean tools for mining

| | |
|---|---|
| Common lean tools in manufacturing | - 5S (Five S)<br>- VSM (Value Stream Mapping)<br>- SMED (Single Minutes Exchange of Dies)<br>- Kaïzen<br>- TPM (Total Productive Maintenance) |
| Lean tools used in mining | - 5S<br>- VSM<br>- LIC (Lean Information Center)<br>- Kaïzen<br>- TPM |
| Proposed lean tools for mining | - 5S<br>- VSM<br>- LIC<br>- SMED<br>- Kaïzen<br>- TPM |

### *3.2. Lean phases*

In the manufacturing industry, lean is implemented in four different phases (Mostafa et al., 2013). Seifullina et al. (2018) suggested a framework with four lean implementing phases for the mining sector as well. Having a framework for adapting lean is useful to assign each tool to its related lean phase. These phases are the conceptual phase, lean pre-integration phase, lean integration and evaluation phase, and final transformation and sustainability of lean phase (Seifullina et al., 2018). The first phase comprises the basic steps needed to start lean implementation within a mine. This includes training the relevant workers and explaining the importance of the lean concept to them. In the second phase, the lean team starts the lean practice by using decision-making tools. Identifying the links between different kinds of wastes and the lean practices is an important step in this phase. Tools such as VSM, LIC can be implemented at this stage (Maunzagona et al., 2017; Dunstan et al., 2006). The third phase is the actual implementation. A pilot project to integrate lean is recommended for this phase to investigate the efficiency and the accuracy of lean implementation. Lean tools such as 5S, TPM, and SMED can be used at this stage (Brodny et al., 2016; Chlebus et al., 2015; Dunstan et al., 2006). Eventually, the last phase includes establishing standards and documenting the experiences gained during the lean implementation. The Kaïzen tool can be implemented in this phase (Castillo et al., 2014; Dunstan et al., 2006). To have a sustainable result after implementing lean tools, the next cycle of lean implementation must be started using the experience and documents obtained from the previous attempts (Vinodh et al., 2011). There is a connection between workplace OHS conditions and the sustainability of lean tool implementation. As sustainability increases, the OHS conditions potentially improve (Sakouhi et al., 2016). Only certain tools can be used in each phase of lean implementation. Choosing a proper tool also depends on the progress level and the needs of companies (Mostafa et al., 2013). Figure 2 shows the different phases for each proposed lean tool for a mine.

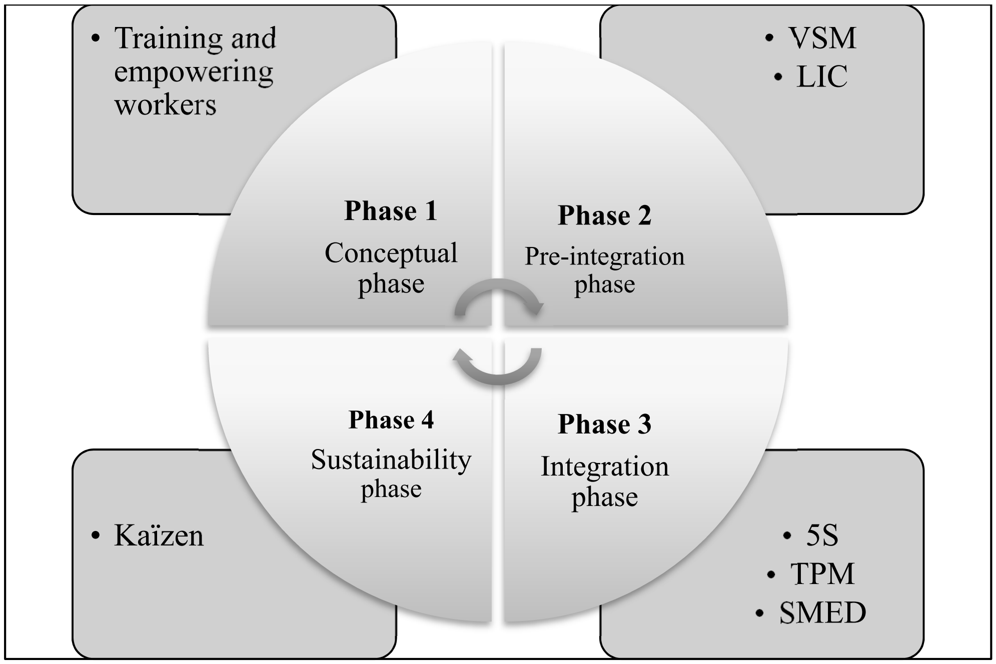


Figure 2 – Proposed lean lifecycle and different implementation phases of each lean tool for a mine

## 4. Discussion

As previously mentioned, there are procedural and environmental differences between manufacturing and mining operations. Unlike the manufacturing sector, the mining process of extraction is usually cyclical with unavoidable stops between each cycle (Flynn et al., 2015). These stops are considered as a form of waste in production (non-value added activities), but they are necessary to perform the required set up for the next cycle (e.g. ventilation of dusts and gases after each explosion, performing quality control). Therefore, a good way to implement lean tools would be to decrease the set up time between each cycle and try to extend the operation time at every cycle to reduce waste and increase production (Lööw, 2015). Available literature about lean mining usually addresses the economic aspect of using lean tools (Brodny et al., 2016; Castillo et al., 2014; Liu, 2013; Ade, 2012; Dunstan et al., 2006). To the best of our knowledge, studies about the impacts of lean tools on OHS in mining are limited. For instance, incident rate reduction (Dunstan et al., 2006), miners' health enhancement (Flamarion et al., 2008), and improvement of safety conditions (Vaněk et al.,

2015) were reported as the possible effects of implementing lean tools on miners' OHS conditions. However, to the best of our knowledge, no other details about the actual outcomes of using lean tools over the long term have been published as of yet. One possible explanation is that the standard methods currently available are insufficient to enable the implementation of lean tools in this field (Lanke et al., 2016).

There are certain limitations in this study. The information obtained in this paper are limited to literature written in the English language. There might be other publications in another language about lean mining which were not considered in this study. The proposed lean tools in this paper are based on the findings from the available literature. There might be other tools not included in this paper that can be used for implementing lean in mining. This needs to be investigated further through different case studies or expert elicitation. Future studies could focus on investigating the possible connections between lean tools and OHS in mining at different phases of lean implementation to reveal the best lean tools integrated with miners' OHS conditions.

## 5. Conclusion

Lean management in mining is still an emerging process. Unlike the manufacturing sector, publications about using lean tools in the mining industry are scarce. Based on the available literature, VSM, LIC, 5S, TPM are selected lean mining tools that have been used by a few mining companies with promising economic outcomes. Given the success of SMED in manufacturing, a proposal about possibly using SMED in an underground mining environment was made, in particular, to reduce the change time of the drill bit and water spray system on a jumbo drill. This can result in an improvement in OHS conditions and productivity. Lean tools should be used based on the company's needs and the current phase of lean implementation. To achieve sustainable results after lean tools have been implemented, the next cycle of lean implementation needs to be started using experiences and documents obtained from the previous attempts. Maintaining the sustainability of the results can have positive effects on miners' OHS conditions as well. More studies are required to investigate the possible link between implementing lean tools and OHS conditions in a mining environment.

## 6. Acknowledgment

The authors would like to thank Mrs. V.T.M. Ngô, a research professional from École de technologie supérieure for her helpful advice and contribution. They also wish to thank the Natural Sciences and Engineering Research Council of Canada and École de technologie supérieure for their financial support.

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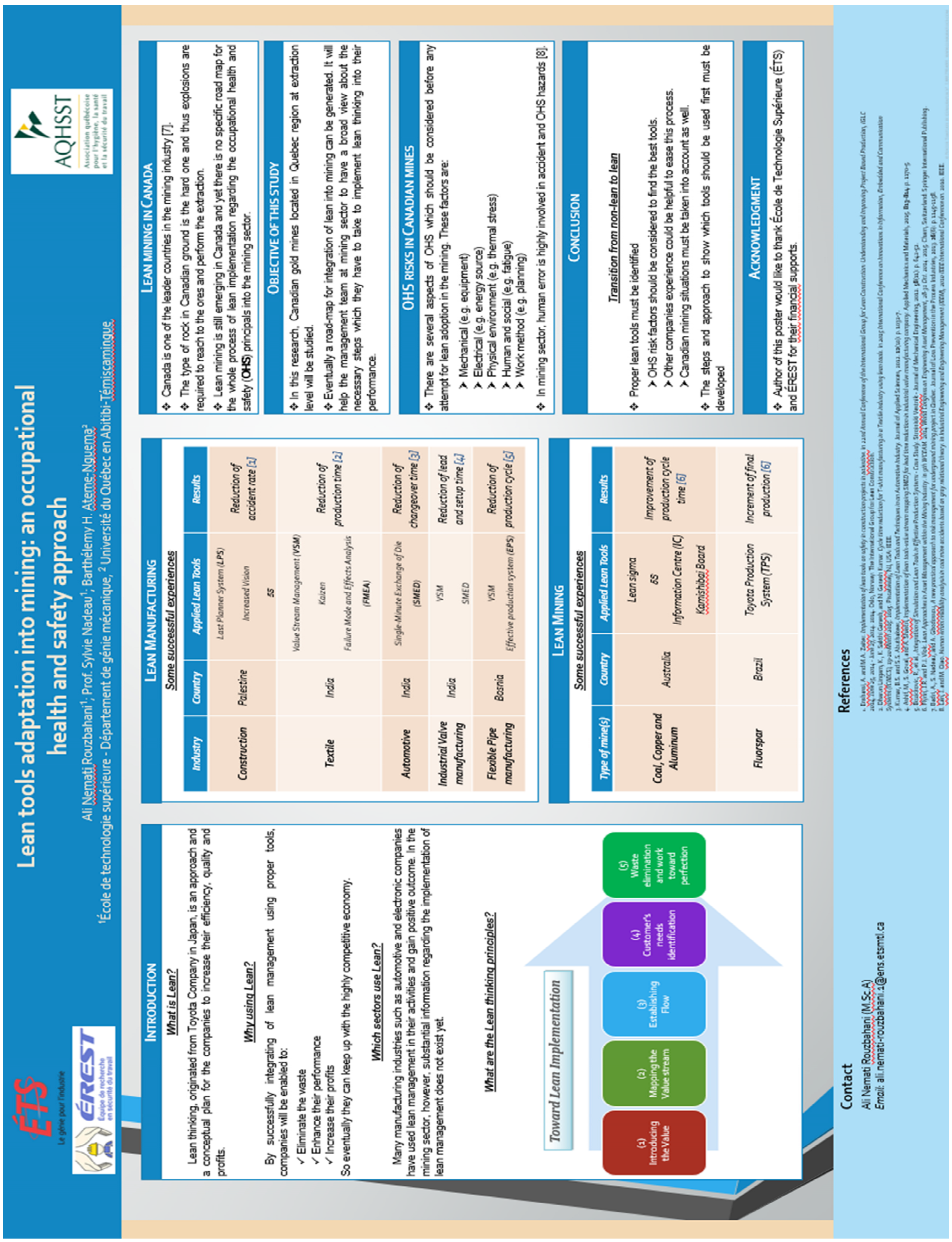
## APPENDIX III

## POSTER IN ANNUAL CONFERENCE OF AQHSST 2017



# APPENDIX IV

# APPROVAL OF THE ETHICS COMMITTEE FOR RESEARCH

ÉTS
Le génie pour l'industrie

**Comité d'éthique de la recherche**
**École de technologie supérieure**

14 septembre 2018

**Titre du projet :** Lean tools adaptation into mining: an occupational health and safety approach

**Responsable :** Sylvie Nadeau

**Numéro de référence :** H20180105 **Type de demande :** *Modification*

**APPROBATION FINALE**

Madame Nadeau,

Une demande de modification au projet de recherche mentionné en rubrique a été déposée le 28 août 2018 pour évaluation par le Comité d'éthique de la recherche de l'ÉTS (CÉR). La présente lettre est pour vous informer que le CÉR a procédé, le 13 septembre 2018, à l'évaluation du dossier en comité restreint.

Liste des documents soumis :

- Formulaire de suivi éthique
- Formulaire de présentation modifié
- Formulaires de consentement modifiés
- Questionnaire d'entrevue
- Courriel de recrutement

J'ai le plaisir de vous informer que, suite à l'analyse des documents soumis, la demande de modification a été **acceptée sans condition**.

Vous trouverez, jointe à la présente, une copie des formulaires d'information et de consentement **approuvés par le CÉR** (*version PDF datée du 14 septembre 2018*). Veuillez utiliser ces documents pour le recrutement de vos participant(e)s.

Veuillez agréer, Madame Nadeau, l'expression de mes sentiments les meilleurs.

Mathias Glaus, Ing., Ph.D.
Président, Comité d'éthique de la recherche

**APPENDIX V**

**SEMI-DIRECTED INTERVIEW QUESTIONNAIRE**

## Informations générales

Interview number : ______________________________
*Numéro de l'entrevue*

Sex : ☐ Male/*Homme* ☐ Female/*Femme*
*Sexe*

Age : ______________________________
*Âge*

Sector/department : ______________________________
*Secteur/département*

Position : ______________________________
*Poste occupé*

Years of experience in the current position : ______________________________
*Nombre d'années d'expérience au poste actuel*

Total years of experience in mining : ______________________________
*Nombre d'années d'expérience dans les mines*

## **Lean dans le secteur minier**

1. How would you describe Lean?
*1. Comment décririez-vous le Lean ?*

Comment:__________________________________________________________________

2. Have you had any Lean training?
*2. Avez-vous suivi une formation sur le concept Lean ?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:__________________________________________________________________

3. How do you describe the current level of lean in Canadian underground gold mining?
*3. Comment décririez-vous le niveau actuel du Lean dans l'exploitation aurifère canadienne (mines souterraines) ?*

Comment:__________________________________________________________________

4. Do you have any vision of what it is going to look like when Lean is implemented in the Canadian underground gold mining?
*4. Avez-vous une idée de ce à quoi ressemblerait une organisation une fois le Lean implanté dans le secteur aurifère canadien ?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:____________________________________________________________

5. Do you know about the type of tools which are being used for implementation of lean in mining?
*5. Savez-vous le type d'outils utilisés pour la mise en œuvre du Lean dans l'exploitation minière?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:____________________________________________________________

6. Do you see any barriers/challenges to succeeding with the Lean implementation?
*6. Voyez-vous des obstacles/défis potentiels pour réussir l'implantation de l'approche Lean ?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:____________________________________________________________

## Les indicateurs de santé et sécurité au travail (SST)

1. How would you describe the current level of safety and health in Canadian underground gold mining?
*1. Comment décririez-vous le niveau actuel de santé et sécurité dans l'exploitation aurifère souterraine canadienne ?*

Comment:________________________________________________________________

2. Is there any health-related issue connected to the Lean implementation?
*2. Y aurait-il un problème de santé lié à la mise en place de l'approche Lean ?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:________________________________________________________________

3. Do you think there could be a link between using the Value Stream Mapping (VSM) and the rate of struck by objects among miners in Canadian underground gold mining?
*3. Croyez-vous qu'il pourrait y avoir un lien probable entre l'utilisation de la cartographie de la chaîne de valeur (VSM) et le nombre (taux) de mineurs frappé par un objet dans les mines d'or souterraines du Canada?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:________________________________________________________________

4. Do you think there could be a link between using 5S and the rate of struck by objects among miners in Canadian underground gold mining?
*4. Pensez-vous qu'il existerait un lien entre l'usage de la technique des «5S» et le nombre (taux) de mineurs canadiens frappés par un objet dans les mines d'or souterraines du Canada ?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:________________________________________________________________

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5. Do you think there could be a link between using kaïzen and the rate of struck by objects among miners in Canadian underground gold mining?
*5. Serait-ce possible qu'il existe un lien entre l'utilisation des ateliers kaïzen et le nombre (taux) de mineurs canadiens frappés par un objet dans les mines d'or souterraines du Canada?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:________________________________________________________________

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6. Do you think there could be a link between using the Total Productive Maintenance (TPM) and the rate of struck by objects among miners in Canadian underground gold mining?
*6. Croyiez-vous qu'il y aurait un lien entre l'utilisation de la maintenance productive totale (TPM) et le nombre (taux) de mineurs canadiens frappés par un objet dans les mines d'or souterraines canadiennes ?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:________________________________________________________________

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7. Do you think there could be a link between using the Single Minute Exchange of Die (SMED) and the rate of struck by objects among miners in Canadian underground gold mining?
*7. Y'aurait-il un lien entre l'utilisation des techniques de réduction des temps de mise en route (SMED) et le nombre (taux) de mineurs canadiens frappés par un objet dans les mines d'or souterraines ?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:________________________________________________________________

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8. Do you think there could be a link between using Lean Information Center (LIC) and the rate of struck by objects among miners in Canadian underground gold mining?
*8. Pensez-vous qu'il existe un lien entre l'utilisation d'un centre d'information Lean (LIC) et le nombre (taux) de mineurs canadiens frappés par un objet dans les mines d'or souterraines du Canada?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:________________________________________________________________

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9. Do you think there could be a link between using Value Stream Mapping (VSM) and the rate of body reaction among miners in Canadian underground gold mining?
*9. Y'aurait-il un lien entre l'utilisation de la cartographique de la chaîne de valeur (VSM) et le nombre (taux) de mineurs canadiens ayant eu une réaction corporelle dans les mines d'or souterraines du Canada?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:__________________________________________________________________

10. Do you think there could be a link between using 5S and the rate of body reaction among miners in Canadian underground gold mining?
*10. Pensez-vous qu'il pourrait y avoir un lien entre l'utilisation de la technique des «5S» et le nombre (taux) de mineurs canadiens ayant eu une réaction corporelle dans les mines d'or souterraines du Canada?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:__________________________________________________________________

11. Do you think there could be a link between using kaïzen and the rate of body reaction among miners in Canadian underground gold mining?

*11. Existerait-il un lien entre l'utilisation des ateliers kaïzen et le nombre (taux) de mineurs canadiens ayant eu une réaction corporelle dans les mines d'or souterraines du Canada?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:__________________________________________________________________

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12. Do you think there could be a link between using Total Productive Maintenance (TPM) and the rate of body reaction among miners in Canadian underground gold mining?
*12. Croyez-vous qu'il existerait un lien entre l'utilisation de la maintenance productive totale (TPM) et le nombre (taux) de mineurs canadiens ayant eu une réaction corporelle dans les mines d'or souterraines du Canada?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:______________________________________________________________

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13. Do you think there could be a link between using Single Minute Exchange of Die (SMED) and the rate of body reaction among miners in Canadian underground gold mining?
*13. Pensez-vous qu'il existerait un lien entre l'utilisation des techniques de réduction des temps de mise en route (SMED) et le nombre (taux) de mineurs canadiens ayant eu une réaction corporelle dans les mines d'or souterraines du Canada?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:______________________________________________________________

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14. Do you think there could be a link between using Lean Information Center (LIC) and the rate of body reaction among miners in Canadian underground gold mining?

*14. Croyez-vous qu'il y aurait un lien entre l'utilisation d'un centre d'information Lean (LIC) et le nombre (taux) de mineurs canadiens ayant eu une réaction corporelle dans les mines d'or souterraines du Canada?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:______________________________________________________________________

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## Indicateurs économiques

1. How would you describe the current economic situation of Canadian underground gold mining?
*1. Comment décririez-vous la situation économique actuelle de l'exploitation minière aurifère canadienne ?*

Comment:______________________________________________________________________

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2. Is there or would there be any economic-related issue connected to the Lean implementation?
*2. Y aurait-il un problème économique lié au déploiement (mise en œuvre) de l'approche Lean?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:______________________________________________________________________

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3. Do you think there could be a link between using Value Stream Mapping (VSM) and the daily advance rate in Canadian underground gold mining?
*3. Pensez-vous qu'il y aurait un lien entre l'utilisation de la cartographique de la chaîne de valeur (VSM) et le taux d'avance quotidien dans les mines d'or souterraines du Canada?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:______________________________________________________________________

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4. Do you think there could be a link between using 5S and the daily advance rate in Canadian underground gold mining?
*4. Pensez-vous qu'il pourrait y avoir un lien entre l'utilisation de la technique des «5S» et le taux d'avance quotidien dans les mines d'or souterraines du Canada?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:______________________________________________________________________

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5. Do you think there could be a link between using kaïzen and the daily advance rate in Canadian underground gold mining?
*5. Croyez-vous qu'il existerait un lien entre l'utilisation des ateliers kaïzen et le taux d'avance quotidien dans le secteur aurifère d'or souterraines du Canada?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:______________________________________________________________________

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6. Do you think there could be a link between using Total Productive Maintenance (TPM) and the daily advance rate in Canadian underground gold mining?
*6. Pensez-vous qu'il pourrait y avoir un lien entre l'utilisation de la maintenance productive totale (TPM) et le taux d'avance quotidien dans les mines d'or souterraines du Canada?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:________________________________________________________________

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7. Do you think there could be a link between using Single Minute Exchange of Die (SMED) and the daily advance rate in Canadian underground gold mining?
*7. Croyez-vous qu'il y aurait un lien entre l'utilisation des techniques de réduction des temps de mise en route (SMED) et le taux d'avance quotidien dans les mines d'or souterraines du Canada?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don't know (*Ne sait pas*)

Comment:________________________________________________________________

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8. Do you think there could be a link between using Lean Information Center (LIC) and the daily advance rate in Canadian underground gold mining?
*8. Pensez-vous qu'il pourrait y avoir une relation entre l'utilisation d'un centre d'information Lean (TIC) et le taux d'avance quotidien dans les mines d'or souterraines du Canada?*

☐ Yes/*Oui* ☐ No/*Non* ☐ Not sure/I don’t know (*Ne sait pas*)

Comment:____________________________________________________________________

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