

# Lean Mining, Productivity and Occupational Health and Safety: An Expert-Elicitation Study

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## 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 are scarce. Consequently, the impacts of using lean tools on productivity and workers' health and safety in this field are still unclear and need more investigations to better integrate the technical aspects of lean with Occupational Health and Safety (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, Kaizen, 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 sector. 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 Kaizen.

## Keywords

Lean Mining, Lean Tools, Occupational Health and Safety, Expert Elicitation, Preliminary Road-Map, Underground Gold Mine

## 1. Introduction

Lean manufacturing is originating from Toyota Motor Company. It was initially known as Toyota Production System (TPS) (Ohno, 1988) [1] and it started when

Toyota discovered shortcomings in the Ford system especially with regards to employees participation. The Toyota management team then 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) [2] [3]. 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) [4] [5]. 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) [6]. Bhamu *et al.* (2014) [5] and Hodge *et al.* (2011) [7] summarize that tools such as five S (5S), Value Stream Mapping (VSM), Kaizen, 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.

## 2. Literature Review: Lean Mining

There are plenty of publications on the results of lean tools in the manufacturing sector (Flynn *et al.*, 2015) [4]. However, for the mining industry, there is little information and very few studies about lean implementation (Löow, 2018; Hasle, 2014) [8] [9]. Sanchez *et al.* (2004) [10] mention that it might be possible to implement the principles of lean equally in every industry. On the other hand, Hattingh *et al.*, (2010) [11] 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) [12] point 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) [13] [4]. 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) [14] [15] [16]. 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) [13] [15]. **Table 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) [16].
- *5S*: Process time reduction in a coal mine (Liu, 2013) [17] and incident rate reduction in an aluminum mine (Dunstan *et al.*, 2006) [16].
- *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) [18] and production rate increase in a coal mine (Ade, 2012) [15] and possible cycle time reduction in a diamond mine (Maunzagona *et al.*, 2017) [19].

- *Kaizen*: In conjunction with other tools such as VSM and 5S, using Kaizen resulted in project performance and productivity enhancement in a copper mine (Castillo *et al.*, 2014) [14] and possible improvements in the miners' health and safety conditions (Vaněk *et al.*, 2015) [20].
- *TPM*: Repair time reduction in a copper mine (Chlebus *et al.*, 2015) [21].

It is important to mention that there are certain differences in the legislative, environmental and geological conditions in each country specified in **Table 1**. Therefore, comparing these results may be difficult without considering these differences. Moreover, there are some drawbacks and limitations in the implementation of lean mining (Hines *et al.*, 2018) [22]. There are different definitions of lean in the literature (Stone, 2012) [23]. Bhamu *et al.* (2014) [5] 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) [24]. 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) [24]. Stahl *et al.*, (2015) [25] 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

**Table 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
Australia	Aluminum	LIC, 5S, TPM	Performance improvement (in early stage of lean implementation)	57% decrease in the rate of incidents among miners	[16]
Australia	Bauxite	LIC & 5S	Cycle time reduction	-	[16]
Australia	Underground copper mine	LIC	56% enhancement in the cycle time	-	[16]
Brazil	Fluorspar	VSM	43.6% raise in productivity	-	[18]
Brazil	Amethyst	VSM	16.6% improvement in the process added-value time	Possible enhancement in the miners' health due to reduction of dust	[18]
Chile	Copper	VSM, 5S, Kaizen	Enhancement in project performance and productivity	-	[14]
China	Coal	5S	16.5% reduction in processing time	-	[17]
Czech Republic	Coal	Kaizen	-	Possible enhancement in the miners' safety and health conditions	[20]
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	[15]
Poland	Copper	5S, TPM	Decrease in average repair time	-	[21]
South Africa	Diamond	VSM	Cycle time reduction	-	[19]

improving their productivity. This approach can lead to limited and unsustainable results (Mazzocato *et al.*, 2010; Repenning *et al.*, 2001) [26] [27].

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) [28] [29]. The employees' overall safety and health can be negatively affected by improper implementation of lean (Adler, 1999) [30]. Increasing the accident and injury rate in the workplace (De Treville *et al.*, 2006) [31], deteriorating the level of health and increasing the stress level of employees (Brenner *et al.*, 2004) [32], and adding onto the workload and intensity of the employees' job (Brännmark *et al.*, 2012; Westgaard *et al.*, 2011) [33] [34] have all reported 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) [13]. 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) [15] [16] [18] [20]. 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. Methodology

#### 3.1. Research Method: Identifying Variables

As previously mentioned, information about the implementation of lean tools in mining regarding OHS issues is scarce in the literature (Nadeau *et al.*, 2015) [13]. Therefore, to gain in-depth knowledge about this subject for this paper, a qualitative research approach was followed (Creswell, 2013; Fortin, 2010) [35] [36]. 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 (O'Hagan *et al.*, 2006) [37]. 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.

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) [13]-[17] [21]. VSM, 5S, Kaizen, TPM and LIC are, in the literature, a pre-selected set of tools to be studied as an independent variable. Moreover, based on a pro-

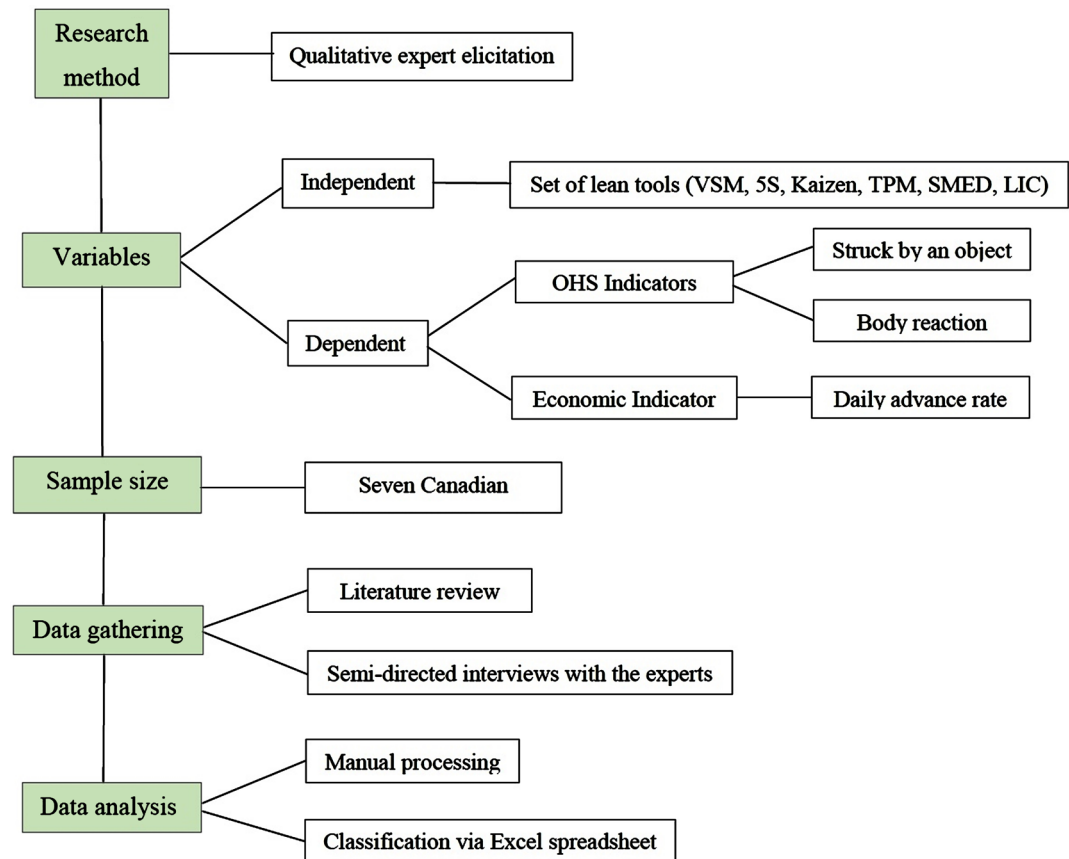
posal by Nemati *et al.* (2019) [38] as to the possibility of using SMED in an underground mining environment, this tool was added to the list of lean tools as an independent variable as well. To investigate the relationships between these tools and economic and OHS indicators in the mining environment, 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) [39] [40]. 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) [41]. 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) [41]. Consequently, the advance rate per day was chosen as the economic dependent variable.

### 3.2. 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 (a representative sample size Lehto & Buck, 2008; Nielsen, 1993) [42] [43] were interviewed for this project. These experts were chosen amongst active academia and practitioners in the mining sector. 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) [44]. 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 1** shows the different steps of the methodology of this research.

## 4. Results

As mentioned above, a semi-directed questionnaire was distributed to the experts. The experts' average age was 55 ( $\pm 13$ ). They had an average of 20 ( $\pm 15$ ) years of experience in the mining sector. 43% of them are active academia and



**Figure 1.** Methodology diagram of this research.

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 precisely 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 2**.

**Table 2.** Available Results summary of experts' opinions regarding the relationship between lean tools and OHS and economic indicators.

Dependent variables		OHS Indicators		Economic indicator
Independent variables		Struck by an object	Body reaction	Daily advance rate
A set of lean tools	VSM	<ul style="list-style-type: none"> <li>57% did not know if there was a link.</li> <li>It depends on the mine.</li> </ul>	<ul style="list-style-type: none"> <li>71% did not know if there was a link.</li> </ul>	<ul style="list-style-type: none"> <li>71% did not know if there was a link.</li> <li>It can increase the paper work.</li> </ul>
	5S	<ul style="list-style-type: none"> <li>57% did not know if there was a link.</li> <li>It might be difficult to sort the mining supplies.</li> </ul>	<ul style="list-style-type: none"> <li>43% did not think there was a link.</li> </ul>	<ul style="list-style-type: none"> <li>43% believed that there is a link.</li> <li>It can increase productivity.</li> </ul>
	Kaizen	<ul style="list-style-type: none"> <li>57% agreed that there is a link.</li> <li>Elimination of bottleneck.</li> <li>Better understanding of tasks and responsibilities.</li> </ul>	<ul style="list-style-type: none"> <li>43% did not know if there was a link.</li> </ul>	<ul style="list-style-type: none"> <li>43% did not know if there was a link.</li> <li>43% believed that there could be a positive link.</li> </ul>
	TPM	<ul style="list-style-type: none"> <li>43% did not know if there was a link.</li> </ul>	<ul style="list-style-type: none"> <li>43% did not know if there was a link.</li> <li>43% believed that there is no link.</li> </ul>	<ul style="list-style-type: none"> <li>57% agreed that there is a link.</li> <li>It can increase the daily advance rate.</li> </ul>
	SMED	<ul style="list-style-type: none"> <li>57% did not know if there was a link.</li> </ul>	<ul style="list-style-type: none"> <li>86% did not know if there was a link.</li> </ul>	<ul style="list-style-type: none"> <li>57% did not know if there was a link.</li> </ul>
	LIC	<ul style="list-style-type: none"> <li>57% did not know if there is a link.</li> </ul>	<ul style="list-style-type: none"> <li>57% did not know if there is a link.</li> </ul>	<ul style="list-style-type: none"> <li>43% did not know if there is a link.</li> </ul>

#### 4.1. 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.

#### 4.2. 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, in the experts’ perspective, implementing 5S elements in the workplace should improve the daily advance rate.

#### 4.3. Kaizen

More than half of the experts (57%) agreed that a link exists between Kaizen 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 Kaizen. 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 Kaizen 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 Kaizen could improve productivity and enhance efficiency through continuous improvement practices.

#### 4.4. 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.

#### 4.5. 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.

#### 4.6. 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, **Figures 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 (**Figure 2**), “body reaction” risks (**Figure 3**) and the daily advance rate in the Canadian underground gold-mining sector (**Figure 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 are 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

**OHS INDICATOR: STRUCK BY AN OBJECT**

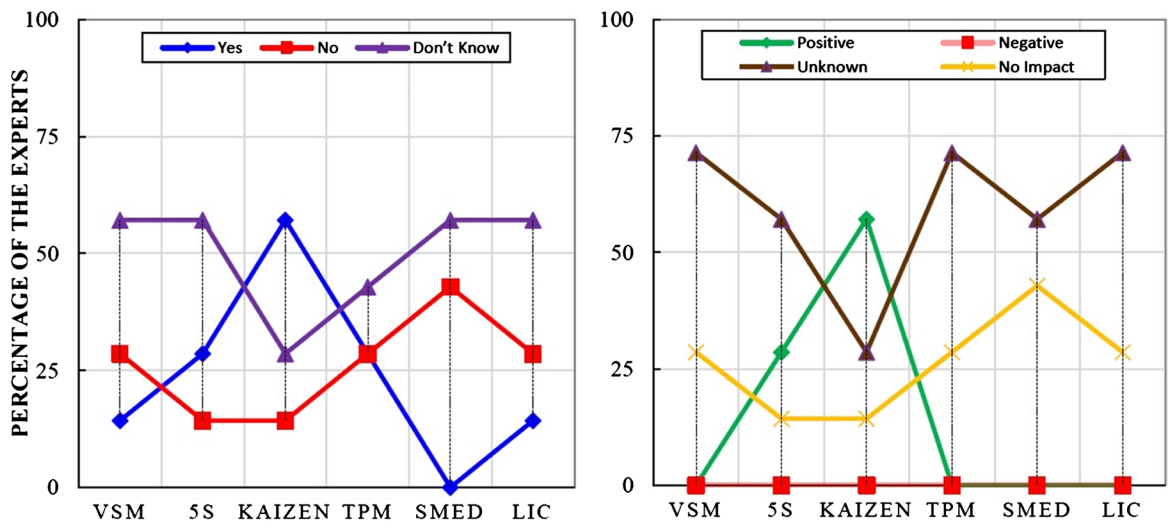


Figure 2. Experts' opinions about the possible connections (left) and the predicted impacts (right) of implementing a set of lean tools on "struck by an object" among workers in the Canadian underground gold-mining sector.

**OHS INDICATOR: BODY REACTION**

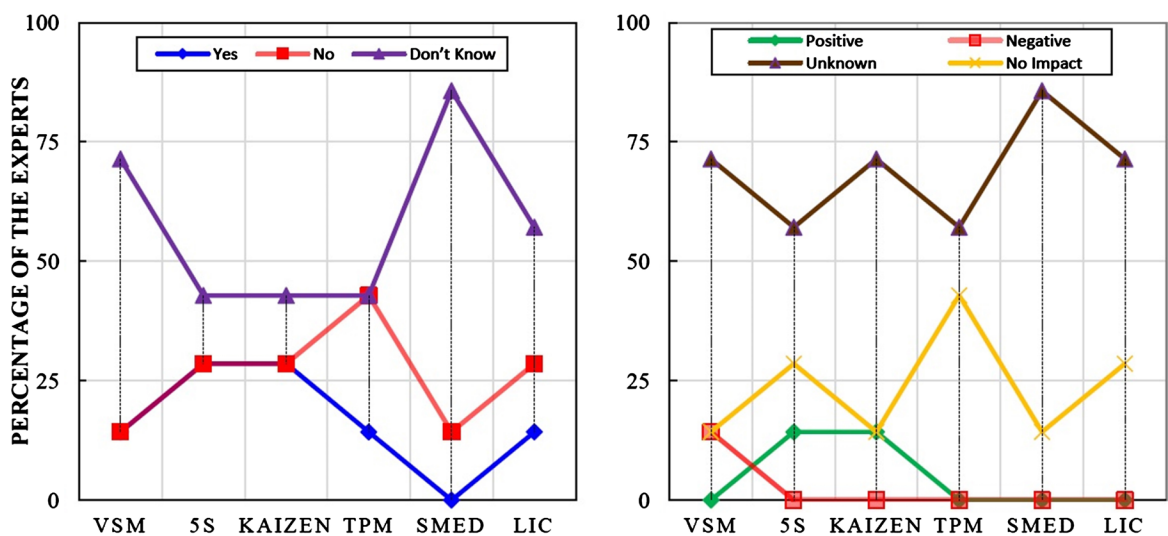
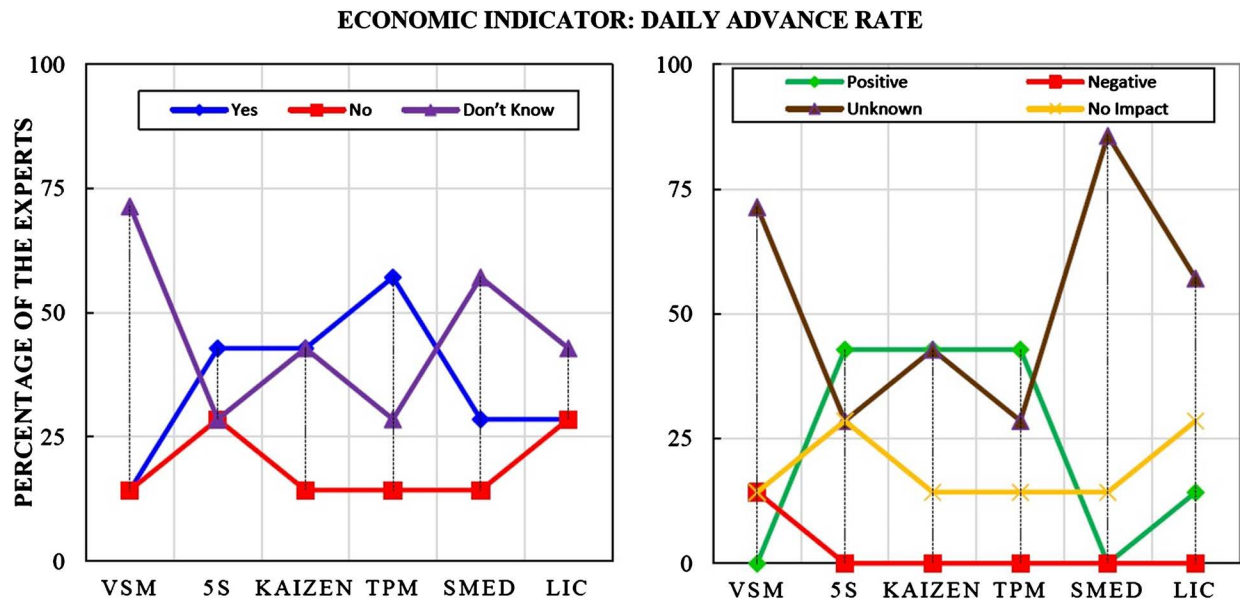


Figure 3. Experts' opinions about the possible connections (left) and the predicted impacts (right) of implementing a set of lean tools on "body reaction" among workers in the Canadian underground gold-mining sector.



**Figure 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.

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 if there is a link between the implementation of lean and these two OHS indicators in mining (**Figure 5(a)**).

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) [45] [46]. On the other hand, the experts' opinions on a relationship between the economic indicator and lean implementation are 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 (**Figure 5(b)**). An overview of the obtained results of this research is presented in **Figure 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.

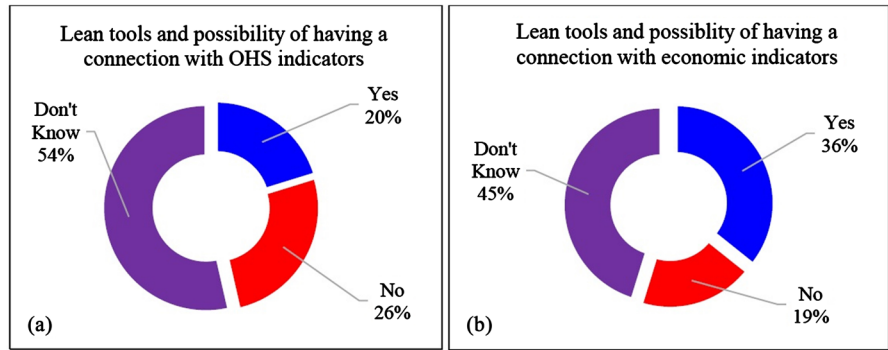


Figure 5. Experts' overall opinions regarding the existence of a possible connection between the set of lean tools, the two OHS indicators and the economic indicator in underground gold-mining environment (respectively (a), (b)).

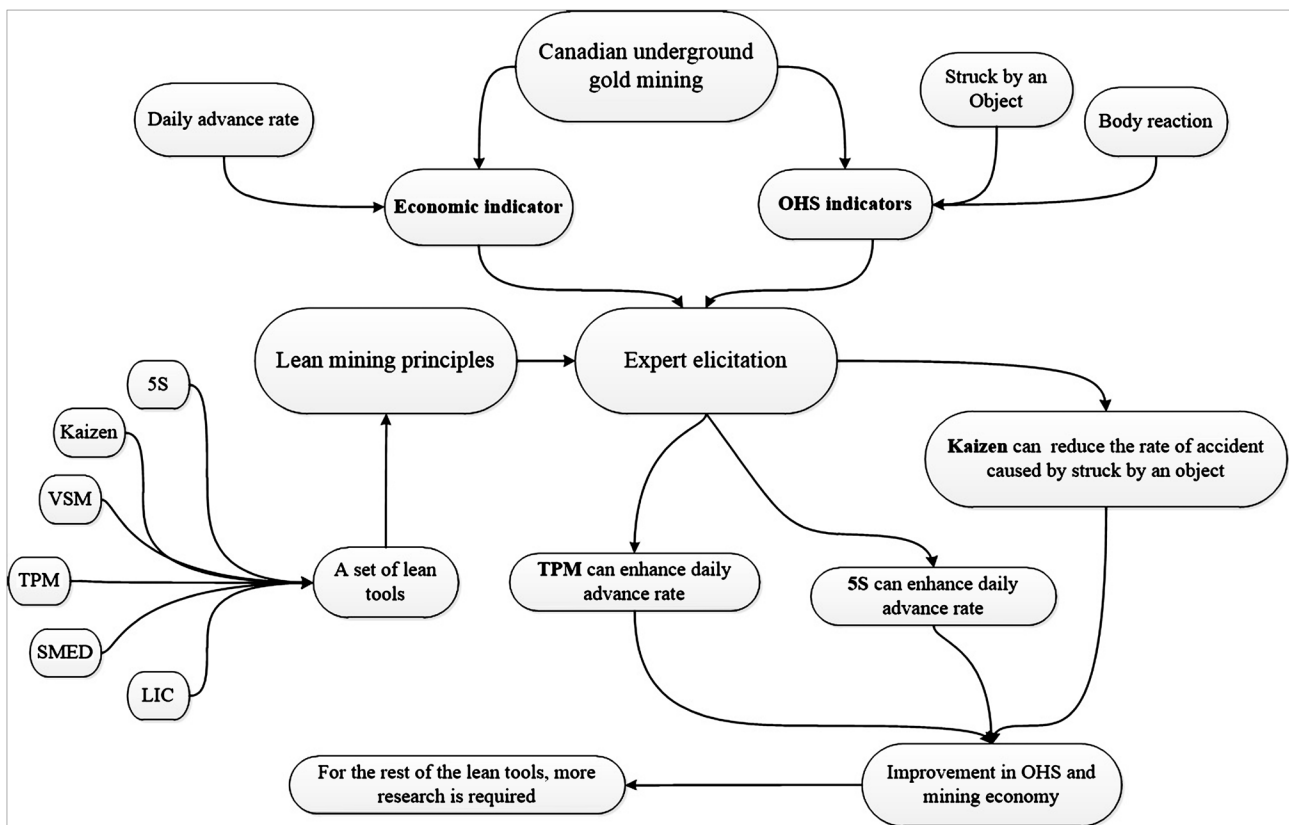


Figure 6. A preliminary road-map (created via mind-mapping) to implement lean mining, based on the findings of this study.

## 5. Discussion

### 5.1. Limitations and Biases

Initially, a total of 10 experts were recruited. 7 experts completed the questionnaire. The scientific community in lean mining in Canada is limited. 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) [47]. 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) [48]. 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) [45]. 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) [24]. 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.

## 5.2. Literature Comparison

By comparing the findings of this study (**Table 2**) with the literature (**Table 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) [16] [17] [21]. The same results for these tools were obtained in this study for underground gold mining. As for Kaizen, a possible improvement in miners' safety and health conditions was reported by Vaněk *et al.* (2015) [20] in coal mining. Decreasing the rate of the risk of being struck by an object after implementing Kaizen was one of this research's findings.

## 5.3. 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. 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.

## 6. Conclusion

Unlike the manufacturing sector, there are little information and studies about the outcome of lean integration in the other sectors. Moreover, implementing lean into Canadian mining sector is still emerging. To the best of 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 Kaizen 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 Kaizen 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.

## Acknowledgements

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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