Exploring Technology Adoption in Canada’s Mineral Mining Sector: Navigating Through an Interplay of Factors

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

The mining sector is currently experiencing a period of disruption where technological innovations such as electric vehicles, artificial intelligence, and drones are transforming how the industry operates. Little is known, however, about the factors that drive, enable, and impede technology adoption in the mining sector, particularly in the context of Canada. To address this gap, this research explores the drivers, enablers, and barriers to technology adoption in Canada's mineral mining sector through an online survey, structured by the technology-organization-environment (TOE) framework, with insights from similar research in the context of Australia. The findings of this research suggest that the top three technologies being adopted by mining companies in Canada are battery electric vehicles (BEV's), sensors, and autonomous equipment. In the Canadian context, the technology adoption process for mining companies is influenced by a complex interplay of factors determined by the three commonly cited dimensions of sustainability (economic, social, environmental). While economic considerations, such as productivity and efficiency, to reduce operating costs and competitive pressures underpin technology adoption decisions, mining companies are also motivated to adopt technologies by social factors such as improvements to health and safety for workers, and environmental factors such as to reduce diesel emissions. Economic factors, such as costs of the technology, implementation costs, limited internal capital, and the capital-intensive nature of the sector, underpin the barriers to technology adoption for mining companies with operations in Canada. This research concludes with suggestions for future research, and key theoretical contributions.

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Chapter 1: Introduction

1.1 Background and Context

The mining sector is currently in an “age of disruption” where technological innovations such as electric vehicles, artificial intelligence, autonomous equipment, drones, and machine learning are transforming how the industry operates (Deloitte, 2015; Clifford et al., 2018) by improving sustainability (Sanchez and Hartlieb, 2020), increasing efficiency, reducing costs for companies, and transforming work (Young and Rogers, 2019). In response, there has been a growing interest among researchers and policymakers to better understand the drivers and barriers to technology adoption in the mining sector (Gruenhagen and Parker, 2020). Tornatzky et al. (1990) refer to the adoption of technologies that are new to an organization as technological innovation, defined as “the situationally new development and introduction of knowledge-derived tools, artifacts and devices by which people extend and interact with their environment” (p. 11). In this definition, technologies, as knowledge-embedded tools, are influenced by a combination of social, behavioural, and physical elements. Rather than understand the technologies themselves, this research aims to better understand the processes of technology adoption by exploring the drivers, enablers, and barriers to technology adoption in the Canadian mineral mining sector.

Technology adoption in the mining sector is a small yet growing field of research, which suggests a rising interest in the topic and vast opportunities for future research. More specifically, Gruenhagen and Parker (2020) identify a gap in the literature on technology adoption and innovation in the mining sector in their systematic review. In addition, according to Steen et al. (2018), innovation in the mining sector occurs differently compared to other industries, which highlights the need to conduct research on technology adoption specific to the mining sector. Furthermore, innovation varies from company to company in the mining industry (Lala et al., 2016). More specifically, as Bergek et al., (2015) argue, technology adoption is context-specific and depends on political, contextual, sectoral, and geographical structures unique to each industry, which suggests a need for research specific to the Canadian context.

It has been argued in the literature that the mining sector is slow to adopt modern technologies (Steen et al., 2018). The literature on technology adoption in the mining sector describes a risk-averse, “conservative” culture with a slow approach to technology adoption (Amadi-Echendu, 2011; Sanchez and Hartlieb, 2020) due to structural barriers such as firm inertia (Gruenhagen and Parker, 2020), high capital intensity (Bartos, 2007; Kinnunen and Kaksonen, 2019; Gruenhagen et al., 2022), risks to health or safety of workers in the case of emergent technologies (Gruenhagen et al., 2022), and traditional styles of management and operations (Gruenhagen and Parker, 2020). The literature also describes the mining sector as reluctant to innovate due to factors such as a business culture that favours established technologies, processes, and short-term innovation investments (Steen et al., 2018). In addition, Ediriweera and Wiewiora (2021) highlight sector-specific factors, such as the geographically remote nature of mine sites or the cyclical nature of commodity prices, as barriers to technology adoption for mining companies in Australia.

Economists largely agree that technologies play a key role in long-term sustainable development (Anadon et al., 2016; Bongomin et al., 2020) and “perpetual” economic growth

(Sachs and MacArthur, 2002; Broughel and Thierer, 2020). For companies, technological innovations are central to improving processes, enhancing productivity, and maintaining a competitive advantage (Dodgson, 2000; Coccia, 2021). More recently, some have argued that technological innovations are central to business success and continuity (Saleem et al., 2021). For the mining industry, technological innovations can offer solutions to industry specific challenges such as environmental impacts, health hazards, and declining productivity (Ediriweera and Wiewoira, 2021; Gruenhagen and Parker, 2020; Aznar-Sanchez et al., 2019). For instance, the difficulties that come with lower-grade mineral and metal deposits in geographically remote and isolated areas could require new technologies such as advanced analytics and sensors (Gruenhagen and Parker, 2020; Kurkkio et al., 2014). More specifically, new technologies such as GPS surveying, drones, and down-hole seismic imaging have enabled firms to reduce the environmental impact of exploration activities, locating new mineral deposits that otherwise would have not been identified through traditional mining methods (Doagoo et al., 2022). While autonomous haulage trucks have effectively reduced operating costs for mining companies in Australia (Hyder et al., 2019).

Additional examples in the literature of the successful adoption of specific technologies by mining companies include machine learning (ML), artificial intelligence (Dehran et al., 2018), autonomous applications (Rogers et al., 2019), drones (Shahmoradi et al., 2020) big data management (Qi, 2020), and the industrial internet of things (IIOT) (Deloitte, 2019). Moreover, there is a consensus in the literature and in practice that technology adoption is critical for the future of the mining sector (Ediriweera and Wiewoira, 2021; Gruenhagen and Parker, 2020). Yet, alongside drivers to adopt advanced technologies are significant challenges that hinder technology development and transformation in the mining industry, such as increased costs associated with adoption, uncertainty and risk, \particularly with new technologies (Ediriweera and Weiwoira, 2021; Gruenhagen and Parker, 2020). Little is known, however, about technology adoption in the mining sector in Canada, including what is driving and impeding the adoption of new technologies for mining companies in Canada (Gruenhagen et al., 2020; Fernandez, 2020; Fitzpatrick, 2011).

1.2 Research Objectives and Questions

To address this gap, this research explores the drivers, enablers, and barriers to technology adoption in the mining sector in the Canadian context.[1] More specifically, this research will answer the following research questions:

(1) What technologies are being adopted in the mining sector in Canada?

(2) What is driving the adoption of these technologies?

(3) What factors are barriers to the adoption of new technologies?

(4) What factors are enablers to the adoption of new technologies?

To answer these questions, this research is informed by an online survey distributed via Qualtrics to mining sector representatives in all provinces and territories, with the exception of the Northwest Territories and Nunavut[2]. This research followed a similar approach to

[1] This research is specific to the Canadian mineral mining sector and excludes oil and gas mining.

[2] The Northwest Territories and Nunavut both have additional research requirements for researchers to obtain a research license, including online survey research. Due to time considerations, these two territories were not included in this research.

Ediriweera and Wiewiora (2021) and used the technology-organization-environment (TOE) framework to identify drivers and barriers to technology adoption related to the technology, the organization and the external environment. This research study is also part of a larger, national research study entitled, *Remote Controlled: Technology in the Mining Sector and the Future of Development in Rural and Northern Regions*, led by Dr. Heather Hall at the University of Waterloo.[3] I turn now to a discussion of technology adoption in Canada and the mining sector in Canada to provide context.

1.3 Technology Adoption in Canada

Canada has been referred to in the literature as "a country of perpetual pilot projects" in terms of its approach to business development and commercialization across all industries (Begin et al., 2009). Lagging innovation, and technology adoption by Canada's business sector has been well documented in the literature for decades, yet the argument remains the same: Canada underperforms in industrial innovation and technology adoption in comparison to other countries. Indeed, Canadian business is "only as innovative as it has needed to be" (Nicholson, 2018, p. 19). A report by the Council of Canadian Academies (CCA) (2009) identifies that Canadian firms lag in technology adoption due to Canada's "upstream" position in the North American economy, a failure to adopt innovative business strategies and a small and geographically fragmented domestic market. A more recent report by the CCA (2018) suggests that while Canada continues to underperform in industrial R&D investment and innovation in comparison to other OECD countries, certain sectors such as

[3] For more information, please visit the Remote Controlled Mining website.

agriculture, finance and insurance have increased their productivity growth through the adoption of more advanced technologies and new production methods (p. 68). Their report (2018) suggests that while Canada is highly innovative, there are significant barriers that impede the translation of R&D activities into technological innovations in the Canadian context. Their report did not however, discuss the barriers to the adoption of technological innovations and instead focused on the barriers to wealth creation, such as the economic integration of the United States and Canadian markets, a lack of management skills and experience, and the high rate of foreign acquisition of Canadian firms. As such, within the discourse on innovation in Canada, technology adoption is largely neglected (Munro and Lamb, 2022).

The economic integration of Canadian and the United States' markets have led to implications for technology adoption by firms in Canada. Nicholson (2016) explains that the deep integration of the North American economy has led Canadian firms to adopt a branch-plant mentality where firms focus their efforts on resource extraction, processing, or assembly rather than on the development of advanced end-products. Canada's natural resource sectors are particularly prone to the branch-plant mentality where there is a tendency to focus on the extraction of raw materials rather than the production of processed goods (Nicholson, 2016; CCA, 2018). Additionally, Nicholson (2016) argues that the economic integration of the North American market has resulted in an environment where technology adoption and development decisions are made externally to Canada, while subsidiaries in Canada prioritize incremental improvements to their operations rather than the adoption of more technologies. Nicholson (2016) suggests that due to Canada's small market share, Canada can only be expected to produce a small amount of innovations. Instead, Canada is heavily reliant on effective diffusion, that is "quickly adopting the best the world has to offer and then continually improving and adapting it to Canadian conditions" (Nicholson, 2016, p. 540). As a result, the structure of Canada's economy creates barriers to the adoption of technology for firms, which highlights Canada's long and complicated history with technology adoption.

1.4 A Brief Glance at Technology Adoption in Mining in Canada

The adoption of advanced technologies in mining is not a new phenomenon. While technologies have always played a key role in mining, in the 1990's, mining companies in Canada began to adopt advanced technologies such as robotics, automation, remote operations, and real-time equipment control at comparable levels to NASA (Chaykowski, 2002, p. 592). Even prior to the 1990's, the mining sector in Canada had a long history of innovation and technology adoption. In her book, *Technology on the Frontier: Mining in Old Ontario* (1986) Newell argues that the success of Ontario as a "frontier" mining region throughout the 19th and 20th centuries was dependent on the industries' adaptation to and importation of technologies. Technologies were imported globally then modified to suit the context of Ontario. As a result, mining was characterized by high degrees of local innovation and technology transfer, where developers specialized in the skills required to adopt technologies produced elsewhere (Warrian, 2020). Diffusion mechanisms in the sector at the time identified by Newell (1976) include the importation of innovative technology and equipment; “forward thinking” engineers and geologists; manufacturers and their agents; government; professional industry associations; and skilled migrant workers.

Overall, the drivers for technology adoption in the mining sector in the 20th century were to improve productivity and operational efficiency at the mine site and increase mineral outputs, process times and quality (Chaykowski, 2002; Warrian, 2020). Large-scale experimentation was the norm, and in some cases took place before the mine was determined to be economically or technically viable. For every success, there were many failures in technology development and adoption (Warrian, 2020). The introduction of industrial engineering led to significant productivity gains for Inco’s Stobie mine in Sudbury, Ontario where productivity doubled from 1940 to 1980. Remote controlled mining[4] led to additional productivity improvements, from 2000 tonnes/year in 1980 to 3,500 tonnes/year in the 1990’s (Chaykowski, 2002). Additionally, industrial engineering introduced new uses for metals and new processing technologies for each stage of the mining process with the intent to lower labour costs, increase productivity and “create new high-value-added applications for its products for manufacturing and consumer markets” (Chaykowski, 2002, p. 6).

Chaykowski (2002) also explored future technology developments in the mining sector, and envisaged the development of a “mine factory” in what he describes as the third stage of technological advancement for the mining sector. This included the anticipated benefits to adopting fully automated and self-deploying mining systems from 2010 onwards,

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[4] Remote controlled mining enables an operator to remotely control machines from the mine face such as drills, bulldozers, or haulers that are located underground; also referred to as teleoperation (DeGaspari, 2003).

which can provide insights into potential drivers and barriers for adoption. The benefits to adopt fully automated technologies were identified as a reduction in energy costs, maintenance costs, labour costs, and an increase in productivity through improved capital utilization, as well as increases in health and safety, pay and training. Chaykowski explains that changes to the organizational structure will reduce low-skilled jobs and create more high-skilled employment, alter work schedules, and enlarge job descriptions. When Chaykowski wrote their article in 2002, the technologies being discussed were in their infancy stage of development. Some suggest that new scientific advances in technologies have enabled the adoption of emerging technologies such as automation, in a mining environment (Ediriweera and Wiewiora, 2021). Since the time of his writing, there have been significant changes in the technological landscape in the mining sector, where new actors, technologies and networks have emerged that require further exploration in the Canadian context.

1.5 Research Contributions

Given these changes and gaps in the literature, this research will make several important contributions to policy, practice, and research. More specifically, this research is expected to provide valuable information to policy makers on the barriers to technology adoption which could lead to policies and programs to address these barriers. For practice, this research intends to identify industry specific drivers and barriers to technology adoption, which could help in the development and procurement of technologies that can ultimately increase productivity, sustainability, safety and efficiency in the industry. Furthermore, this research will help fill a gap in the academic literature on the adoption of technologies in the mineral mining sector in Canada (Gruenhagen et al., 2020). As noted, research on technology adoption in the mining industry is a small yet growing field and Gruenhagen and Parker (2020) highlight the need for context-specific research on the diffusion of innovation and technology adoption in the mining industry. This research will help fill this gap in the Canadian context by adding to the literature on technology adoption.

It is worth noting, that Canada's history is intimately tied to natural resource development (Innis, 1930; Lapalme, 2003). Minerals and metals are the building blocks of our society; providing the raw materials required to build roads, equipment, buildings, and electronics. Canada produces over 60 minerals and metals (MiHR, 2022) and the mining industry is a significant contributor to the Canadian economy (NRCAN, 2022). Canada has abundant deposits of nickel, lithium, manganese, graphite and cobalt, which are the critical minerals required to build clean technologies such as battery electric vehicles (BEVs). In the 2020 Speech from the Throne, the Government of Canada states that Canada's mineral resources are its "competitive edge" as these vast mineral deposits place the country in a unique position where it can gain a competitive advantage in critical minerals and in electric mobility[5] (Government of Canada, 2020; Bains, 2020). At the same time as the world shifts to a low-carbon economy, rising geopolitical tensions and industrialization have led to increased global demands for the minerals and metals required to develop clean technology.

[5] Electric mobility refers to all vehicles powered by an electric motor supplied by the power grid, and comprises of fully electric vehicles and hybrid vehicles (Government of Germany, 2022)

A key focus of the Canadian government is to ensure the transition to a low carbon economy enhances collective economic opportunity and prosperity for Canadians. Federal Budgets of 2021 and 2022 allocate $144.4 million to research and development in mineral exploration, for the development and deployment of advanced technologies in the mining sector. Federal funding programs such as the Critical Minerals Research, Development and Demonstration (CMRDD) Program, developed in 2021, provides funding for companies who are developing advanced technologies for the extraction of mineral resources and technologies that support the development of domestic critical mineral value chains. Additionally, the Critical Minerals Strategy (2023) notes that the realization of Canada's mineral potential, located in rural and remote regions, rests on its ability to harness the adoption of advanced technologies (i.e., internet of things) to reduce costs, improve competitiveness, efficiency, and environmental stewardship of the mining sector. Research on Canada's mining sector is therefore crucial due to the importance of natural resources to the Canadian economy, for its role in supporting a carbon-neutral future and economic prosperity for all Canadians (Government of Canada, 2023; World Bank Group, 2017).

For industry, this research identifies challenges and opportunities with technology adoption that could assist with procurement, efficiency, productivity, health and safety, environmental stewardship, and sustainability (Job and McAree, 2017). In addition, this research provides the mining industry with knowledge on what factors enable technology adoption in Canada, as well as what factors act as barriers in the decision to adopt emerging technologies. As suggested by Deloitte (2017), innovation through the adoption of more efficient and sustainable technologies will allow the mining industry to improve its operations which could increase the supply of critical minerals. Additionally, this research provides insights into the industry for policymakers on the innovation supports needed for technology adoption and what opportunities new technologies provide for the mining industry in Canada. With greater insight into the industry, policymakers can make better informed decisions with regards to policy direction and improve relationships with stakeholders in the mining industry.

1.6 Thesis Outline

This thesis seeks to better understand and identify the factors that impact technology adoption in the context of the Canadian mineral mining industry. More specifically, this thesis seeks to identify key technologies that are being adopted by mining companies in Canada, as well as to better understand the drivers, barriers and enablers to technology adoption in the Canadian context. Chapter 2 provides an overview of the existing literature on defining technology adoption, as well as a discussion on the current state of technology adoption research. This includes an overview of the commonly used models, theories and frameworks to better understand technology adoption at the individual and organizational level. Chapter 2 also provides an overview of the framework used to guide this research, the TOE framework, along with a justification for the use of the TOE framework and its limitations.

Chapter 3 discusses the methodology used to respond to the research questions that guide this research. This chapter provides an overview of the research paradigm, methodology, and survey design. More specifically, this research is guided by the pragmatic paradigm, and employs a cross-sectional survey approach to answer the research questions. The chapter concludes with a discussion on the methods of data collection, which consisted of both in person and online recruitment, and the sources of data, which consisted of mining company representatives, mining supply and services (MSS) company representatives, technology company representatives, non-profit organization (NGO) representatives, government representatives and technology providers. Results to the survey can be found in Chapter 4, which includes an analysis of common themes identified in the findings as well as some similarities and differences between the results to this survey and the existing literature. Finally, Chapter 5 discusses the key findings, limitations, and areas for future research.

Chapter 2: Literature Review

2.1 Introduction

As mentioned in the previous chapter, this research is focused on exploring the drivers, enablers and barriers to technology adoption in the mining sector. This chapter begins with defining innovation, diffusion, and technology adoption. Following this, is an overview of the literature on the drivers and barriers to technology adoption at the firm-level that are most discussed in the literature. Then, a summary of the models and theories developed by scholars to better understand, predict, and explain technology adoption is provided. An overview of these models and theories shows that not only is the literature highly fragmented across disciplines such as information systems, innovation, management, and sociology, but that the majority of existing models have been developed to better understand technology adoption at the level of the individual rather than the company or firm. Following this, is an introduction to the Technology-Organization-Environment (TOE) framework developed by Tornatzky and Fleischer (1990) with insights from the Diffusion of Innovation (DOI) Theory by Everett Rogers (2003), as well as a discussion of its limitations and overall justification of its use in the context of this research. The remainder of this chapter is focused on technology adoption in the mining sector, with an emphasis in the literature on the drivers, enablers and barriers.

2.2 Definitions

This section provides an overview of several key definitions that help to inform this research. Key definitions are provided for innovation, technology, adoption, and diffusion. Additionally, this section discusses the relationships between these terms and describes their relevance to this thesis. This section concludes with a discussion on the importance of technology adoption for countries and for firms.

2.2.1 Innovation

Innovation is defined in the *Oslo Manual* (2018) as “a new or improved product or process (or combination thereof) that differs significantly from the unit’s previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)” (p. 20). In other words, innovation can be defined as a product or a process, that introduces a sense of newness to the world or to a region (Hall et al., 2016). A product innovation is defined by the OECD/Eurostat (2005) as “a good or service that is new or significantly improved. This includes significant improvements in technical specifications, components and materials, software in the product, user friendliness or other functional characteristics” (p. 48) while process innovations are defined as “a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software” (OECD/Eurostat, 2005, p. 49). A product or process is considered an innovation when it has been implemented (introduced in the market) and is new to a specific firm (OECD/Eurostat, 2018). From an economics perspective, innovations can be understood along a continuum of incremental to radical innovations. Radical innovations introduce an entirely new product or process to a market, while incremental innovations are the constant improvements to a given product or process (Nicholson, 2018). I turn now to defining technology in more detail.

2.2.2 Technology

Tornatzky et al. (1983) define *technology* broadly as “any tool or technique, any physical equipment or method of doing or making, by which human capability is extended (Schon, 1967)” (p. 1). In this definition, technologies are at their core a cognitive construct, limited to those with linkages to the practice of basic or applied science (Tornatzky and Fleischer, 1990). According to Tornatzky et al. (1983), technology is defined in a broad sense because “technology concerns more than just hardware inputs and outputs of production operations; it includes also the functions that tools serve to improve organizational performance, and the interactions that tools have with their social setting” (p. 3). More recently, a working paper by the OECD also defined technology as a broad concept, to refer to the “state of knowledge on how to convert resources into outputs” (Galindo-Rueda et al., 2020, p. 9). Schatzberg (2018) provides a historical overview of technology as a concept from the field of the philosophy of science and states that some researchers define technology in a narrow sense as the “application of science” that is heavily reliant on past scientific discoveries (Schatzberg, 2018, p.1). However, a narrow understanding of technology fails to acknowledge that while science is an important part of technology, it is not the only part (Schatzberg, 2018). To understand technology in a broad sense enables the researcher to expand their perspective and view technology beyond its technical factors to include social and economic factors.

The work by Rogers on the *Diffusion of Innovations* (1995; 2003) includes the role of uncertainty in the definition of technology. Rogers (2003) defines technology as “a design for instrumental action that reduces the uncertainty in the cause-effect relationships involved in achieving a desired outcome” (p. 13). Rogers (1995) emphasizes that technology has an *uncertainty-reduction* effect for adopters due to the information base provided by the new technology. Rogers (2003) further argues that a technology consists of two components, specifically hardware and software. The hardware component refers to the tool's material or physical objects, the semiconductors, electrical connections, transistors and a metal frame to protect the computer. The software component consists of the information base for the tool. In this, according to Rogers (2003) technology represents an interaction between the tool itself and how it is used. On the one hand, new technologies entail a degree of uncertainty with regards to the consequences or outcomes of adoption. On the other hand, the adoption of new technology represents the possibility of solving a perceived problem, which acts as an opportunity to reduce uncertainty.

2.2.3 Adoption

Adoption is defined as "the decision to implement and use a new technology" (Rogers, 1995, p. xviii). Adoption refers to the point in the decision-making process where a user moves from not having a new technology to having it, or the point of purchase of a technology (Tornatzky and Fleischer, 1990). Tornatzky and Fleischer (1990) state that it is difficult to define adoption because adoption is a process involving many indirect and direct decisions that may not be apparent to some participants. Adoption decisions are "not an act of a single decision, or even a simple set of decisions, but rather a highly contingent chain of choices that iterate toward an outcome that is neither inevitable nor even necessarily predictable" (p. 178). In other words, the term adoption includes the decisions that make a technology available to its users and does not refer to a specific decision. For instance, to approve the adoption of a new technology, a company may require approval from different hierarchies of management resulting in multiple points of decision-making along the adoption process (Tornatzky and Fleischer, 1990).

Adoption theory examines the choices that are made when an individual or organization decides to accept or reject a specific technology. Some adoption theories and models focus solely on the decision to adopt a technology (Tornatzky and Fleischer, 1990) while others also include the utilization and implementation of the technology in a specific context (Straub, 2009; Pennington, 2004; Venkatesh et al., 2003). Moreover, Sharma and Mishra (2014) conducted a systematic review of the literature on technology adoption and found that ‘adoption’ and ‘diffusion’ are often used interchangeably, despite their very different meanings. While adoption is defined as “the decision to implement and use a new technology” (Rogers, 1995, p. xviii), diffusion is defined as "the stage in which the technology spreads to general use and application” (Rogers, 2003). In other words, the term adoption refers to the individual or organizational level, while diffusion refers to adoption by the masses (Sharma and Mishra, 2014).

Straub (2009) states that adoption theory more specifically examines the choices that are made when an individual or organization decides to accept or reject a technology, while “diffusion theory describes how an innovation spreads through a population” (p.626). Straub (2009) states that adoption theory, then, “is a micro-perspective on change, focusing not on the whole but rather the pieces that make up the whole” (p. 626). The confusion between adoption and diffusion in the literature likely stems from the origins of adoption and diffusion research. In many respects, Rogers' theory on the Diffusion of Innovations (DOI) serves as the foundation for adoption research (Tornatzky and Fleischer, 1990; Pennington, 2004; Venkatesh et al., 2003). However, some researchers suggest that the DOI is not well suited to examine the adoption of technologies (Straub, 2009), particularly in the context of firms (Oliveira and Martins, 2011). This suggests that there is opportunity to deepen the literature on the adoption process to better understand the drivers, enablers and barriers that arise when organizations adopt technological innovations.

2.3 Importance of Technology Adoption

Technological advancements have long been regarded as the key source of economic growth and increased competitiveness for nations, industries and firms (Solow, 1957; Rosenberg, 1982; Porter, 1985; Tornatzky and Fleischer, 1990; Mitropoulos and Tatum, 1999). More recently, Myovella et al. (2019) studied the impacts of digitization on economic growth in 33 OECD countries and 41 Sub-Saharan African countries and found a positive impact on economic growth in both groups. Some authors argue that technological change through technologies such as information and communication technologies (ICT) are a source of national economic prosperity and can stimulate additional sources of growth (Acemonglu and Robinson, 2013; Arendt, 2015). Additionally, ICT can create competitive advantages for firms through the establishment of more efficient flows in data and information, reducing operating costs, facilitating relationships with other stakeholders, and better managing challenges faced in the external business market (Kutlu and Özturan, 2009). Adeosun et al. (2009) argue that the application of technological innovations such as ICT can improve decision making, knowledge management, data management, access to information, and coordination of tasks for firms. According to Stratopoulos (2016), the rate of adoption of technological innovations has implications for equipment and technology suppliers, investors, and firms due to the possibility that technologies can disrupt the current competitive landscape and provide competitive advantages for adopters. Therefore, the literature suggests that technology adoption plays a significant role in a firm's success.

Technologies also play an important role in promoting sustainability. In the last few decades, sustainability has become a growing concern for society, policymakers, researchers, and industry associations (Söderholm, 2020). More specifically, sustainability as a policy originates in the United Nations' Brundtland Report (1987), which sought to address the tension between the need to address climate change on the one hand, and the desire for improved economic and social conditions on the other. In this context, sustainability encompasses "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987, p. 45) and integrates the environmental, economic, and social dimensions of sustainability. Early research suggests that our ability to reduce our environmental impact and achieve sustainable development will be dependent on the ability to harness technological change (Beder, 1994). More recently, researchers suggest that emerging technologies such as 5G, artificial intelligence, drones, internet of things, and robotics can contribute to progress towards each of the United Nations' Sustainable Development Goals (SDGs) (Al Emran and Griffy-Brown, 2023;

Küfeoğlu, 2022). In the next section I will discuss common drivers to technology adoption based on a brief overview of the literature.

2.4 Drivers for Technology Adoption

Drivers for technology adoption are strongly correlated with the expected or perceived outcomes of adoption (Ali and Aboelmaged, 2022; Romanello and Veglio, 2022), such as increases in productivity, efficiency, sustainability, and a reduction in costs (Culot et al., 2020). In a summary of conference proceedings by the OECD, on the implications of digital technology adoption for businesses in the European Union (EU), the OECD (2018b) identified additional drivers for adoption. These include worker skills, the desire to adopt technologies that improve productivity and the "importance of culture in the adoption of digital technologies" (p. 3). Their study is specific to digital technology adoption by businesses in the EU but suggests that similar research in the context of Canada can inform policy and industry on the opportunities and challenges inevitable in the technology adoption process. The following sections expand on productivity, sustainability, efficiency, and cost reductions as drivers for technology adoption.

2.4.1 Productivity and Efficiency

A primary driver for technology adoption for organizations is to increase productivity. It has been suggested in the literature that the insufficient adoption of technology over the past two decades has contributed to weak productivity growth for firms (Andrews et al., 2016). Some researchers suggest that technology adoption can result in long-term productivity growth for firms (Brynjolfsson and McAfee, 2012; Gal et al., 2019; Sánchez and Hartlieb, 2019) as improved productivity is attributed to greater labour efficiency, resource utilization, and workflow efficiency, which leads to increased output (Bresnahan et al., 2002). A report by the Ontario Chamber of Commerce (OCC) (2022) suggests that the adoption of digital technologies among small businesses in Canada improves labour productivity, which is particularly important in the Canadian context due to low overall productivity growth of businesses in comparison to countries such as the United States. The productivity gap between Canada and the United States has been growing in recent years, where the overall productivity in Canada in 2022 is 72% that of the United States (OECD, 2023).

However, data on the extent to which firms in Canada adopt technologies that improve productivity is limited (Andrews et al., 2018). In the Canadian context, Gu (2019) examines the cause of Canada's decline in productivity since 2000 and attributes the decline in productivity to a decline of innovation diffusion from frontier to non-frontier firms. In addition, the literature shows that productivity benefits from technology adoption vary across Canada. Moshiri (2016) examines the impacts of ICT adoption and the spillover effects on productivity among Canadian firms and found that while ICT has a positive impact on labour productivity across Canada, there is significant variation across provinces, industries, and time. Moshiri (2016) utilizes a panel data estimation model of Canada's 10 provinces with data from 1981-2008 and found that provinces with strong manufacturing and services sectors have greater productivity growth than provinces with strong agriculture and natural resource sectors. Additionally, their analysis shows that primary sector industries such as mining have benefited far less from ICT adoption than manufacturing and service sectors.

Overall, their research shows that the benefits of ICT adoption for productivity are limited to ICT-intensive industries and provinces.

In the European context, Gal et al. (2019) compares firm-level data in various industries across EU countries to identify a link between digital technology adoption and productivity. Productivity benefits were particularly strong in manufacturing and industries that were routine-intensive, while weak in industries with skills shortages. However, as acknowledged in the report by the OECD (2018b) and in the academic literature, technology adoption does not always result in productivity growth. Instead, productivity growth from technology adoption is often a slow, nonlinear process. A decline in productivity growth despite the adoption of new technologies has been referred to in the literature as the "modern productivity paradox" in reference to the original productivity paradox outlined in 1987 by Robert Solow (Acemoglu et al., 2014; Brynjolfsson et al., 2017).

Additionally, Blichfeldt and Faullant (2021) argue that technologies are adopted by firms to increase efficiency in production and commercialization. In their work on European manufacturing firms, digital technologies have led to greater efficiency in production and commercialization processes. They also found that digital technologies are primarily adopted to achieve efficiency gains for firms, which had a direct positive effect on profitability in terms of the return on sales (ROS). Emerging technologies such as machine learning, internet of things, blockchain technology, cloud computing and wireless sensor networks have also improved efficiency in industries such as agriculture and mining. For instance, in farming IoT and sensors have been used to improve water use efficiency (Saurabh and Dey, 2021).

While in mining, virtual representation technology and sensors have enabled firms to increase safety and efficiency through the establishment of real-time remote monitoring of geographically remote mine sites (Prinsloo et al., 2019). Some researchers suggest that efficiency gains from technologies are largely determined by the integration of the technology with existing tools (DeLay et al., 2021). In other cases, technological innovations did not improve productivity or efficiency for firms because the technologies were not leveraged correctly by the firms (Lanfranchi and Grassi, 2021). As a result, the impact of specific technologies on efficiency is not entirely agreed on in the literature.

2.4.2 Cost Reduction

The economics literature suggests that cost reduction is one of the main competitive priorities for firms, and that technologies are adopted by organizations in cases where the technology is expected to reduce the costs of production or increase product output (Chavas and Nauges, 2019; Zheng et al., 2021). The adoption of new technologies can lead to cost savings with respect to labour, resources, time, and waste management (Bademosi and Issa, 2021). Several technologies in various industries have been analyzed in the literature and have shown to reduce costs for firms. For example, Baumers et al. (2017) investigates the impacts of the adoption of additive manufacturing (AM) in comparison to conventional processes in the manufacturing sector and identified that AM adoption can result in a 36-46% reduction in total costs for firms. Similar findings have been cited in the agricultural sector where the priority for technology adoption is to reduce costs (Chavas and Nauges, 2019). In many cases, the economic benefits from adoption (i.e. fuel savings, yield increases) can outweigh the drawbacks of high upfront investment costs to adopt the technology (Paustian and Theuvsen, 2016). In another example, Zemlyak et al. (2022) investigates the adoption of collaborative robots (cobots) in manufacturing and identified how cobots can create competitive advantages for firms through cost reduction, which can lead to further competitive advantages such as improvements in the quality of production output, flexibility, and increase innovativeness. Overall, cost reduction is a commonly cited driver for technology adoption in the existing technology adoption literature.

2.4.3 Sustainability

As mentioned, sustainability has become a growing concern for society, policymakers, researchers, and industry (Söderholm, 2020; European Commission, 2019). The literature suggests that sustainability is a driver for technology adoption in a variety of sectors such as agriculture (Aaubert et al., 2012; Cole and Fernando, 2021; Martos et al., 2021), construction (Li et al., 2022), and manufacturing (Braccini and Margherita, 2019) and can have a positive impact on each of the three dimensions of sustainability (Li et al., 2022). Technologies such as precision agriculture have been found to improve efficiency and environmental sustainability for farms in Alberta, with positive implications for sustainability (Nicol and Nicol, 2021). In another study, the adoption of Industry 4.0 (I40) technologies in the manufacturing sector in Italy contributed to the economic dimension of sustainability through improvements in productivity and product quality, the environmental dimension through improvements in data precision and continuous energy consumption monitoring, and the social dimension through a safer work environment, reduction of accidents, and greater job satisfaction for workers (Braccini and Margherita, 2019).

In addition, the research by Braccini and Margherita (2019) revealed that the three dimensions of sustainability support and reinforce each other. More specifically, the authors identify “more efficient production and higher quality products” (p. 12) as a driver for I40 adoption, which supports the economic dimension of sustainability by differentiating their company with competitors,[6] the environmental dimension through a reduction in waste and use of natural resources, and the social dimension through greater job satisfaction, paid taxes, and localized production. Their interviews with management emphasize the importance of sustainability goals in the design phase of I40 adoption and suggest I40 sustainability benefits are limited to cases where sustainability is included in the design phase of technology adoption. Their case study was focused on one company; therefore, their results could not be generalizable for the manufacturing industry, where differences in firm size, industry, regulatory environments, and location of company can lead to variation in technology adoption decisions and practices.

Other research suggests that technologies can positively impact one dimension of sustainability and simultaneously negatively impact another dimension (Bai et al., 2023). For instance, robotics and artificial intelligence can improve environmental sustainability in the automotive industry while at the same time lessen employment opportunities and hinder

[6] Competitors took a different approach than adopting I40. Instead, they delocalized production to other countries with lower wage requirements, which had the effects of lower product quality and local job loss.

social sustainability (Bai et al., 2023). Additionally, Bai et al. (2023) argue that the sustainability benefits of I40 technologies are sector-dependent, and that policy makers and practitioners must carefully consider each technology and its implications for sustainability across sectors. Al Emran and Griffy-Brown (2023) employed a bibliometric analysis to explore the opportunities and challenges of technology adoption for sustainability development and their research found that technologies can have either a positive or negative impact on sustainability, however a better understanding of the adoption of these technologies by organizations can lead to improved sustainability outcomes.

The literature further states that technologies, such as blockchain technologies, can improve the sustainability of supply chains and their benefits have been explored in the literature (Marsal-Llacuna, 2018; Saberi et al., 2019; Friedman and Ormiston, 2022). For example, in one study on the adoption of blockchain technology in food supply chains, blockchain technology was proven to improve food traceability, improve environmental sustainability and create more fair supply chains (Friedman and Ormiston, 2022). In the context of the manufacturing sector, the existing literature indicates that additive manufacturing can have significant sustainability benefits for firms. Some researchers, however, have come to conflicting findings on the role of sustainability as a driver for technology adoption. For example, Niaki et al. (2019) sought to explore the role of sustainability in the decision to adopt additive manufacturing for firms. Their research found that sustainability is rarely a driver for adoption, despite the sustainability benefits identified in the literature on additive manufacturing. Implications of their research indicate that economic factors override sustainability factors in the decision to adopt technologies for firms. Therefore, there are some conflicting findings in the literature on the role of sustainability in the decision to adopt technology, which requires further research.

2.5 Barriers to Technology Adoption

While drivers for technology adoption develop from the outcomes expected from adoption, barriers can arise at all stages of the adoption process. These include barriers specific to the technology, economic and financial barriers, risk aversion and uncertainty, and workforce resistance. Additionally, prior to adoption, technologies often require significant upfront investment, time, and demonstration projects throughout the development process before the drivers for technology adoption or expected outcomes can be realized. This section discusses some of the barriers that are commonly discussed in the literature, specifically technical barriers, economic and financial barriers, risk aversion and uncertainty, and workforce barriers.

2.5.1 Technical Barriers

Much of the literature on the drivers and barriers to technology adoption at the firm-level focus on the technical aspects and challenges to adoption (Kiel et al., 2017). In a review on the adoption of Industry 4.0 technologies in the manufacturing industry, technology immaturity was identified as the most significant barrier to adoption (Kumar et al., 2022). Technology immaturity refers to emerging technologies that require further development, have challenges with interoperability, scalability, and usability (Kouhizadeh et al., 2021), or when standards for the technology have yet to be developed or maintained (Wu and Wang, 2005; Agarwal et al., 2023). Technology immaturity can create a negative perception towards the technology and increase perceived risks and hesitation towards adoption, which can lead to a “wait and see” mentality among managers (Tezel et al., 2020). Similar findings have been identified in the construction industry. For example, Bademosi et al. (2021) studied the adoption of robotics and autonomous technologies in the U.S. construction industry and looked at economic, organizational, personnel, technical and operational barriers. Technical requirements, specifically related to the infancy of the technology, as well as economic factors were identified as the top barriers to adoption. Overall, technology immaturity leads to unexpected and increased risks with adoption that may deter potential adopters from investment in the technology.

2.5.2 Economic and Financial Barriers

Several researchers have identified cost as a significant barrier to technology adoption for firms (Ramilo and Embi, 2014; Kiel et al., 2017; Choudhury et al. 2019; Kumar et al., 2022). On the one hand, cost of the technology, implementation, and unclear return on investment can act as barriers to adoption, while cost reductions upon adoption are drivers for adoption (Li et al., 2010). Masood and Sonntag (2020) conducted a survey of UK SMEs based on the technology acceptance model (TAM) to identify the challenges of Industry 4.0 adoption. They found that financial and knowledge limitations are the most significant barriers to adoption, despite a desire to implement Industry 4.0 technologies. Knowledge limitations develop when workers lack the skills or experience required to operate a newly adopted technology. Additional barriers noted in their survey include cyber security concerns, complexity, firm inertia, the limited time available to dedicate to the development of new technology, and a lack of investment in training and support.

Cost as a barrier to technology adoption has also been noted in the literature by other researchers (i.e. Ozorhon et al., 2016; Kiel et al., 2017; Orzes et al., 2018) where economic and financial barriers to adoption of technologies include high upfront investment costs, a lack of financial resources, and a lack of clarity on the economic benefits of the technology. In other words, the adoption of a new technology requires access to financial resources (i.e. funding) and creates uncertain profitability for firms (Kiel et al. 2017). Some researchers also argue that the adoption of technological innovations requires the upskilling or retraining of workers, which can create additional costs following adoption (Toufaily, 2021).

Table 1 summarizes the costs of adopting a new technology in the context of the construction industry.

Table 1: Costs of Technology Adoption for Firms

Cost Category	Cost Factors
Initial investment	• Complexity of the technology • Compatibility of the technology • Initial cost
Operating cost	• Cost for consulting services • Cost for training personnel • Cost of implementing supporting infrastructure
Maintenance cost	• Regular inspection and maintenance of equipment • Service after breakdown • Equipment repair and parts replacement • Upgrading of the technology

Source: Bademosi and Issa (2021) p. 6.

More specifically, Bhattacharya (2012) studied the adoption of RFID-related activities and identified costs and difficulties monetizing the benefits of a technology as the most significant factors that impact adoption decisions. It’s important to note that the adoption of a specific technology can have several associated costs. For example, the costs of RFID adoption include the initial purchase cost, the software required, installation costs and maintenance costs. Further, the high costs of technology implementation can increase significantly in cases where the technology is adopted across the supply chain (Bhattacharya, 2012). Similar cost constraints are identified in the literature on firm adoption of industrial internet of things (IIoT) adoption (Kiel et al., 2017), robotics (Delgado et al., 2019), and Industry 4.0 technologies more generally.

Given these costs, it can be difficult to justify the return on investment (ROI) for technologies, which can ultimately be a barrier to adoption (Fitzgerald et al., 2014; Reyes et al. 2016; Horváth and Szabó, 2019). For example, Makinde et al. (2022) analyzed the adoption of digital technologies in the Canadian beef industry and found that while the upfront investment costs act as a barrier to adoption, results from their survey and interviews indicate that an unclear ROI is a more significant barrier than the upfront costs of the technology. As a result, existing literature suggests that financial constraints, such as a lack of access to funding and high investment costs can pose barriers to technology adoption.

2.5.3 Risk Aversion and Uncertainty

Risk aversion and uncertainty have also been recognized in the literature as significant challenges to technology adoption (Barham et al., 2014; Marra et al., 2003). For firms that are already operating profitably with current technologies, the likelihood of adoption decreases (Ediriweera and Wiewoira, 2021). Due to the uncertainties and risks inevitable in adopting technological innovations, some firms may choose to disregard opportunities for future growth in favour of immediate gains, which creates a barrier to technology adoption (Ediriweera and Wiewoira, 2021). I now turn to a discussion on workforce barriers.

2.5.4 Workforce Barriers

The adoption of a new technology can create internal disruption and inevitable changes to organizational structure. For example, the adoption of Industry 4.0 technologies can result in a shift in production systems from centralized to decentralized control. Any structural change within an organization can be faced with workforce resistance, which results from either satisfaction with the current system or a lack of the necessary skills (Prause, 2019). Research demonstrates that workforce resistance to a new technology will ultimately result in a decrease in overall productivity, regardless of whether the technology facilitates workers in their tasks. For example, Trist (1981) studied the implementation of the "Longwall Method" in a coal mine, where miners shifted from the traditional method of extraction to a mechanized method. Productivity drastically decreased due to a reduction in worker satisfaction. As a result, workforce resistance due to changes in the structure of work and legacy thinking can create challenges for firms when adopting new technologies (Basole and Nowak, 2018). Furthermore, new technologies also often require new skills. Carroni et al. (2023) state that shortages in specialized labour is one of the main barriers to technology adoption for firms. While Beaudry (2010) also argues that despite the benefits of digitalization, U.S. firms do not adopt digital technologies due to a lack of specialized skills. I turn now to a discussion of the more common technology adoption models and theories, particularly the TOE, which informs this research.

2.6 Technology Adoption Models and Theories

The existing literature on technology adoption is highly fragmented (Van Oorschot et al., 2018). There are several theories and models in the information systems literature that seek to understand the interactions between technologies, organizations, and people through a systems perspective. The academic discipline of information systems is an interdisciplinary field that gains insights from technical fields such as management science and social sciences such as economics, sociology, and psychology (Straub, 2009). Theories and models in the information systems literature in the context of technology adoption allows researchers to better understand and predict the behaviour of an individual or organization as to whether they will accept or reject a new technology (Masimba and Zuva, 2021). Models include the Technology Adoption Model (TAM) (Davis, 1986), the Theory of Planned Behaviour (TBP) (Ajzen, 1991), the Diffusion of Innovation (DOI) Theory (Rogers, 1995; 2003), and the Technological, Organizational, and Environmental (TOE) framework (Tornatzky and Fleischer, 1990). The most cited theories on technology adoption are illustrated below in Table 2.

Table 2. Common Technology Adoption Theories and Models

Framework/Theory	Key Sources	Level of Analysis	Description of Framework
Diffusion of Innovations (DOI)	Rogers (1960, 1995, 2003)	Individual (1960) and Later (1995, 2003) Organization	Seeks to understand how an innovation spreads throughout a population. Emphasis is on how technologies spread through social systems (interpersonal communication). Identifies that relative advantage, ease of use, compatibility with existing processes, trialability and observability enable the diffusion, or spread of an innovation throughout a population (Rogers, 2003). Separates the population into five segments, namely innovations, early adopters, early majority, late majority, laggards identified by an individual's propensity to adopt innovations.
Theory of Reasoned Action (TRA)	Fishbein and Ajzen (1975); Madden et al. (1992); Hale et al. (2002)	Individual	Seeks to understand behaviours through an analysis of the relationship between an individual's existing attitudes and subjective norms. Suggest that an individual's behavioural intentions derive from their attitudes and subjective norms towards the behaviour (Hale et al., 2002). Criticized in the literature for not being falsifiable (Trafimow, 2009; Ogden, 2003).
Theory of Planned Behaviour (TPB)	Azjen (1991); Azjen (2020); Bosnjak et al. (2020)	Individual	Replaced the TRA. Seeks to explain a person's behaviour; states that behaviour is influenced by one's intention to act on the behaviour and their subjective norms and attitudes towards the behaviour (Fishbein & Ajzen, 1975). Utilized in studies on smoking cessation.
Technology Acceptance Model (TAM)	Davis (1986); Lee et al. (2003); Legris et al. (2003)	Individual	Most influential model to understand technology acceptance. Seeks to understand how individuals come to accept a technology. Posits that perceived ease of use and perceived usefulness determines whether an individual will accept a new computer system (Davis, 1986).
Technology Acceptance Model 2 (TAM2)	Venkatesh and Davis (2000)	Individual	Extension of TAM, includes determinants of perceived usefulness as: subjective norms, image, job relevance, experience and voluntariness (Venkatesh and Davis, 2000).

Technology Acceptance Model 3 (TAM3)	Venkatesh and Bala (2008)	Individual	Extension of TAM2, includes determinants of perceived ease of use as: perceived enjoyment, computer self-efficacy, computer anxiety, perceived enjoyment, effort required to use new system (Venkatesh and Bala, 2008).
Unified Theory of Acceptance and Use of Technology (UTAUT)	Venkatesh (2003); Williams et al. (2015); Dwivedi et al. (2019)	Individual	Developed to better understand technology acceptance and unify the variables of the technology acceptance models. The theory includes the constructs of performance expectancy, social influence, facilitating conditions, and effort expectancy. Moderating variables are age, experience, gender and voluntariness of use, and the theory examines their relationship with "intention to use" (Venkatesh, 2003).
Theory of Task-Technology Fit (TTF)	Cooper and Zmud (1990); Goodhue & Thompson (1995); Furneaux (2012); Spies (2019)	Individual	Seeks to explain technology utilization with an examination of the relationship between technology characteristics and the fit of the technology to a particular task to better understand how technology acceptance impacts performance in organizations (Spies, 2019).
Technology-Organization-Environment Framework (TOE)	Tornatzky and Fleischer (1990); Baker (2012)	Organization	Examines how technology, organization and environment factors influence technology adoption (Baker, 2012). Focus is on the organization as the level of analysis.
Institutional Theory	Ivancou et al. (1995)	Organization	Perceived benefits, organizational readiness and external pressure impacts technology adoption for organizations; focus on interorganizational adoption (Ivancou et al., 1995)

Source: Created by Author.

As demonstrated in Table 2, there is a lack of convergence in the literature with respect to how adoption is measured, defined, and observed (Montes de Oca Munguia et al., 2021). Montes de Oca Munguia et al. (2019) state that this lack of convergence is problematic, as “there is a lack of clarity about the analytical methods and the choice of explanatory variables that we should use to model adoption” (p. 80). In addition, there is no consensus on the specific variables that influence technology adoption, which creates complexities when trying to determine which variables to include for research. The authors identify that variables related to specific technologies are consistently underrepresented in the literature, which is problematic as it suggests that technological innovations are not being properly defined or are poorly understood (Montes de Oca Munguia et al. 2019).

Oliveira and Martins (2011) conducted a review of the technology adoption models at the firm-level derived from the information systems literature to compare the validity of each model. Their review found that the DOI and the TOE frameworks are the most used frameworks at the firm-level in the information systems literature and focused their research on further examination of the existing literature on these two models. At the firm-level, the DOI postulates that the innovativeness of a firm is related to characteristics of the individual decision makers, internal organizational structure, and external characteristics of the organization. Comparatively speaking, the TOE suggests that technology adoption decisions are determined by technology characteristics, factors internal to the organization and factors in the external environment.

Oliveira and Martins (2011) further found that some researchers combine models to better understand technology adoption decisions. For example, Chong et al. (2009) studied the adoption of collaborative commerce and incorporated competitive advantage, compatibility, and complexity from the DOI into the TOE framework. Zhu et al. (2006) studied the adoption and usage of e-business and incorporated relative advantage, compatibility, costs, and security concerns into the TOE framework. While Wang et al. (2010) incorporated relative advantage, complexity, and compatibility into the TOE framework in the technology context to understand RFID adoption. In each example, results on the factors that influence adoption varied. Wang et al. (2010) found that factors related to relative advantage, compatibility and complexity were not significant in the adoption of RFID, while organizational readiness and external environment were strongly associated with adoption. Oliveira and Martins (2011) concluded that as technologies become increasingly complex, future research should combine factors from each model to attain a better understanding of the adoption phenomenon.

This thesis incorporates some insights from the DOI framework; however, the main basis of this research is the TOE framework by Tornatzky and Fleischer (1990). The DOI theory was initially developed to examine technology adoption at the individual level and was later expanded by Rogers (1995, 2003) to the organizational level. Importantly, technology adoption at the firm-level is more complex than at the individual level due to the multitude of decision makers who influence the rate and direction of adoption (Tornatzky and Fleischer, 1990; Rogers, 1995). Rogers (1995) states that technology adoption is influenced by compatibility, observability, complexity, relative advantage and trialability, which equate with the TOE framework's technological context (Baker, 2012). These factors are described in more detail in the section below.

2.6.1 Insights from the Diffusion of Innovations (DOI) Framework

Rogers (2003) defines **relative advantage** as the extent to which a technological innovation is perceived to be an improvement from the status quo (p. 212). The relative advantage of a technology can be measured by economic factors, social prestige, satisfaction, and convenience. Furthermore, relative advantage is also related to the costs of implementing a technology, a decrease in discomfort, the degree of economic profitability, social prestige, and the immediacy of the reward. According to Rogers (2003), the relative advantage of a technology is less determined by its objective advantage than by the adopters' perceived advantages of the technology.

Compatibility is the extent that a new technology "is consistent with existing values, past experiences, and needs of potential adopters" (p. 224). The compatibility of a new technology with existing technologies, processes and operating systems can influence the decision to adopt a new technology. Rogers (2003) explains that technological innovations with high compatibility entail less uncertainty for adopters, which allows potential adopters to gain familiarity with the innovation. Therefore, the more compatible a technology is with existing practices, the less uncertainty there is in adopting the technology, and the more likely it is to be adopted. Compatibility can have negative effects on organizations when previous experiences of failed technology adoption influence future technology adoption decisions, referred to by Rogers (2003) as "innovation negativism" (p. 227). As a result, Rogers' states that it is important to adopt technologies with a high relative advantage as to highlight technology adoption successes and subsequently build upon them (Rogers, 2003).

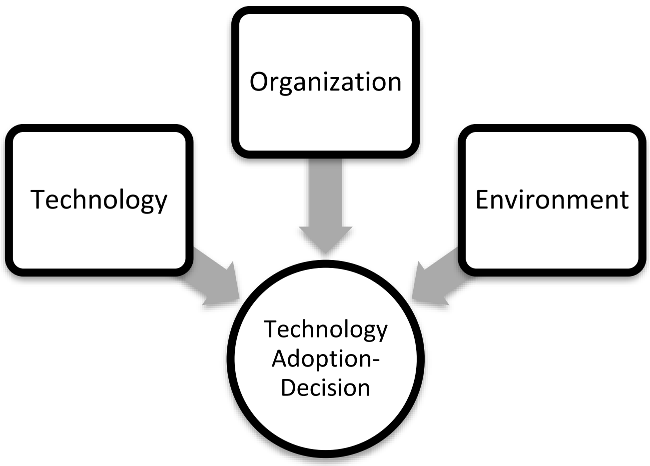
Complexity is defined by Rogers (2003) as "the degree to which an innovation is perceived as relatively difficult to understand and use" (p. 242). According to Rogers (2003), technologies that are more difficult to use are less likely to be adopted by companies than those that are simpler to use. In other words, the more complex the technology, the greater the resistance is to adoption. Additionally, with greater complexities that come with a specific technology, greater managerial skills are required. At the same time, the greater the complexity of a technology, the greater the risk and uncertainty involved in its adoption (Vanclay, 1992). The DOI theory suggests that technological innovations that are simpler to use and understand are adopted more readily than technologies that require the development of new skills (Rogers, 2003).

Trialability occurs when potential adopters can test and experiment with a technology before adoption. Technological innovations are those that can be tried on a partial basis entail less uncertainty for the potential adopter and enable learning by doing (Rogers, 1995). In Rogers' (2003) DOI theory, he suggests that technological innovations that can be trialed before adoption are more readily adopted than technologies that cannot be trialed. Finally, **observability** refers to the "degree to which the results of an innovation are visible to others" (Rogers, 2003, p. 17). The greater visibility of a technological innovation, the more likely it will be adopted as visibility encourages peer discussion and innovation-evaluation. Returning to the main components of a technology, namely hardware (the physical and material component) and software (the information component), Rogers (2003) states that technologies with a larger software component can be more difficult to observe and thus will be adopted at a slower rate. The following section consists of an overview of the technology-organization-environment framework, as well as a critique of the framework and a justification for its use in this research.

2.7 Technology-Organization-Environment (TOE) Framework

To study technology adoption with the organization as the unit of analysis requires a framework that includes organizational and external determinants to technology adoption. The most cited framework in the literature that captures organizational determinants for adoption is the Technology-Organization-Environment (TOE) Framework, first developed by Tornatzky and Fleischer in their book, *The Processes of Technological Innovation* (1990). The TOE framework was initially developed to understand IT (information technology) adoption but has since been adapted for various industries and technologies (Zhu et al., 2006). The TOE framework has been applied to research in industries such as financial services (Zhu et al., 2004), healthcare (Lee and Shim, 2007; Racherla and Hu, 2008), construction (Katebi et al., 2022; Na et al., 2022), manufacturing (Chattergee et al. 2021), agriculture (Mukherjee et al., 2022), and recently, mining (Ediriweera and Wiewiora, 2021). The TOE framework was developed to evaluate, measure, and understand technology adoption at the organizational level. According to the TOE framework, technology adoption decisions are determined by a range of factors that are categorized into technology, organization, and the external environment (Tornatzky and Fleischer, 1990). Each of these categories are discussed in more detail below.

Figure 1: Technology-Organization-Environment Framework



Source: adapted from Baker, 2012, p. 6.

2.7.1 Technological Context

The technological context analyzes the characteristics of the actual technology and its subsequent implications for the organization. Tornatzky and Fleischer (1990) state that it is important to consider the technology context as separate from the rest of the environment to "focus attention on how the features of the technologies themselves can influence both the adoption process and implementation" (p. 153). The technological context includes both internal and external technologies that are of relevance to an organization. More specifically, this includes technologies used by the organization and current technologies that are available in the market (Baker, 2012). Internal technologies are technologies that are currently in use, and external technologies are those that exist in the market but have not yet been adopted. According to Collins et al. (1988), it is important to consider the technologies already in use by an organization because the current technological context sets the stage for the pace of technological change a company can undertake. Technologies that exist in the market but have not yet been adopted are also important to consider because these technologies can establish the "limits of what is possible as well as by showing firms ways [technologies] can enable them to evolve and adapt" (Baker, 2012, p. 11). In other words, technology adoption decisions depend not only on the technologies that exist in the market, but also how technologies fit within the firm's existing technologies and infrastructure.

According to the original TOE model, the factors that shape the technological context are availability and characteristics (Tornatzky and Fleischer, 1990). Availability refers to the availability of a technology to an organization, which is important because the availability of a technology increases exposure, which increases the potential number of adopters (Sana'a, 2017). Characteristics refer to aspects of the technology itself. Technology characteristics discussed in the technological context of the TOE framework include the technological proficiency required to adopt a new technology (Thong, 1999). The technological proficiency of the individuals adopting and implementing the technology impacts the adoption process in that greater technological proficiency results in smoother technology adoption processes. Related to this, new technologies can be categorized as either "competence enhancing" or "competence destroying." Competence enhancing technologies allow for current skills sets to be built upon and enhanced, while competence destroying technologies may require a different skill set than previous technologies, rendering current skills obsolete (Gatignon et al. 2002). More recently, Awa et al. (2016) analyzed 12 factors commonly cited in the literature on the TOE framework among small-medium enterprises (SMEs) and found that technical know-how, or technical competence is a statistically significant adoption determinant in the technological context of the TOE framework.

2.7.2 Organizational Context

The organizational context refers to the structure and management practices of a given organization and is defined by descriptive variables such as organizational structure, firm size, availability of slack resources, centralization, and formal and informal linkages between employees (Tornatzky and Fleischer, 1990). Existing processes and structures within an organization can either directly facilitate or impede technology adoption. Early research on the relationship between organizational structure and adoption put forth the argument that organizations with organic rather than mechanistic structures are more likely to adopt or introduce technological innovations (Tornatzky and Fleischer, 1990). The organic model of organizational structure is dynamic, with informal communication processes between subunits, decentralized decision-making authority and control, high networking among workers and subunits, and flexibility (Tornatzky and Fleischer, 1990). In contrast, mechanistic organizational structures are formalized and centralized organizations. Formalization and centralization are two commonly studied variables at the organizational level to understand technology adoption (Olson et al., 2005; Lai and Guyness, 1997).

Formalization refers to the defined rules, procedures, and practices within an organization (Rogers, 2003). Formal linking structures represent an organization's division of labour into specific tasks, while informal linking structures represent the naturally occurring patterns of communication structures within an organization. Both informal and formal linking structures enable coordination throughout an organization (Tornatzky and Fleischer, 1990). The formal linking structures of an organization define the degree of flexibility and autonomy with regards to who can make innovation-related decisions and introduce new ideas. The formal structure also determines the degree to which information is exchanged between different stakeholders in the adoption process (Russell, 1990). The formal structure can be examined by the degree of autonomy employees have to initiate and attempt new innovations, such as through decentralized structures.

Informal linking, on the other hand, is defined by the organizational norms and behaviours that facilitate innovation, such as policies, relationships, knowledge sharing, and overlapping experiences (Russell, 1990). Literature suggests that intra-firm linking structures between subunits of a firm facilitate innovation and technology adoption (Baker, 2012). Informal linking agents that encourage the adoption process include product champions, boundary spanners, and gatekeepers (Baker, 2012). Literature suggests that top management support is of critical importance to successful technology adoption because management can provide workers with an environment that encourages innovation. Management can also communicate to workers the value of innovation (Jeyaraj et al., 2006; Sabherwal et al., 2006; Wang et al., 2010). Furthermore, an organization’s intra-firm communication processes transmit knowledge and encourage technology adoption (Tornatzky and Fleischer, 1990).

Centralization occurs when decision making, and leadership is concentrated within a small group of individuals (Rogers, 2003). In their book, *The Management of Innovation* (1994), Burns and Stalker suggest that a high degree of centralization can impede the rate of innovation as it can limit employee opportunity. More recent research on organizational adoption suggests that decentralization encourages collaboration across subunits, greater flexibility and greater autonomy, which are positively correlated to adoption (Ediriweera and Wiewiora, 2021; Baker, 2012). However, some empirical researchers suggest that centralization has no correlation to technology adoption (Lai and Guyness, 1997). The competing perspectives on the organizational determinants of adoption suggest that technology adoption is driven by “contrasting forces and mechanisms” that cannot be explained by a single, overarching set of determinants (Bao, 2009).

Another commonly cited organizational factor is slack resources which is defined as the pool of human or financial resources that exceed the resources required for an organization to successfully operate (Nohria and Gulati, 1996). Slack resources enable “an organization to afford to purchase/develop innovations, absorb failure, bear the cost of instituting innovations, and explore ideas in anticipation and advance of an actual need” (Rosner, 1968, p. 615). Literature varies as to whether slack enables or inhibits technology adoption. On the one hand, slack can facilitate the adoption process as it provides organizations with the resources to adopt technologies, encourages creativity and provides the flexibility required to experiment with technological innovations (Nystrom et al., 2002). For the implementation stage of the adoption process, slack can increase overall technical and organizational preparedness when adopting a technology through the use of past expenditures, and slack can be used to employ managerial or technical consulting services (Nystrom et al., 2002). On the other hand, slack resources can reduce incentives to innovate and result in a lack of discipline, complacency, and inefficient investment in projects with low economic value. That being said, Nohria and Gulati (1996) state that companies do require some slack resources to innovate, because too little slack can deter experimentation with new technologies.

One final factor that is widely studied in the literature is firm size, which is measured by the number of employees in an organization (Tornatzky and Fleischer, 1990; Oliveira and Martins, 2011; Baker, 2012; Cirera et al., 2019). Findings vary as to whether the size of a firm drives or hinders technology adoption. Oliveira and Martins (2011) studied firm adoption of IT and state that firm size impacts how firms invest in and subsequently profit from IT. Some suggest that larger firms are often subject to greater competitive pressure which can positively influence technology adoption (Zahi, 2010; Ruivo et al., 2014; Oliviera et al., 2014; Alsheibani, 2018). Larger firms can drive technology adoption due to greater resource advantages that enable experimentation and implementation of new technologies (Pindado et al., 2010; Sila, 2013). Pindado et al. (2010) examines the influence of firm characteristics on R&D intensity and found that larger firms benefit from economies of scale, R&D cost spreading and greater access to capital markets than smaller firms. Some studies also argue that larger firms have the benefits of greater risk tolerance and greater trading power than smaller firms (Sila, 2013). The literature on technology adoption also examines the moderating effects of firm size on technology adoption. Literature suggests that the size of the firm is particularly important in the context of sustainable technology adoption because larger firms are more likely to participate in international sustainability initiatives, more likely to be scrutinized by the public, while smaller firms are less in the public eye and tend to be followers when it comes to sustainability initiatives (Hao et al. 2020).

Other researchers have come to different findings. Larger firms are seen as "less agile" than smaller firms and are hindered with the possibility of structural inertia that can create lock-in effects with existing technologies. Additionally, structural inertia can result in greater costs and effort associated with implementing a new technology (Zhu et al., 2004, p. 28). However, some researchers have found that firm size has an insignificant effect on technology adoption (Gibbs and Kraemer, 2004; Ifinedo, 2011; Khayer et al., 2021). While the existing literature is unclear as to the role of firm size in the technology adoption process, the literature also suggests that it is important for researchers to consider firm size to prevent unwanted biases in their research findings (Lin et al., 2019). Researchers such as Hao et al. (2020) state that further investigation into the variation in technology adoption and its relationship with firm size is needed in the academic literature.

2.7.3 Environmental Context

The environmental context includes external factors to the organization that either drive or constrain innovation and technology adoption. Tornatzky and Fleischer (1990) identify industry characteristics and market structure, technology support and service providers, and the regulatory environment as important factors influencing technology adoption decisions at the environmental level. Similarly, Damanpour and Gopalakrishnan (1998) identified "environmental change" as a driver for technology adoption in organizations, which is defined as a new idea, service or system that is either developed by the organization itself or purchased externally (Damanpour and Evan, 1984). In other words, change within the environment in which a firm operates can drive or hinder technology adoption. Researchers such as Porter (1980), also argue that a firm's success is largely dependent on how it relates to its external environment, which includes social and economic factors, as well as the industry in which it operates.

More specifically, industry characteristics and market structure refer to the industry in which a firm belongs, as well as the geographical scope of the industry, external support infrastructure and competitive pressures (Tornatzky and Fleischer, 1990; Oliveira and Martins, 2011; Baker, 2012). The influence of market structure and industry characteristics on technology adoption has been studied extensively in the literature (Oliveira and Martins, 2011; Bademosi and Issa, 2022). Oliveira and Martins (2011) state that an industry can significantly influence a firm's approach to technological innovation and adoption. Industries can vary in terms of their technology intensity; some industries are more technologically intensive than others which can impact technology adoption practices. In industries that are typically perceived as technologically intensive, such as financial services or IT, the industry pressures to adopt a new technology can impact a firm's approach to technology adoption and heighten pressure to adopt new technologies (Pan et al., 2022). For example, in the IT sector, pressures to adopt AI increase because the industry has familiarity with IT and the support infrastructure required to enable the adoption of AI (Pan et al., 2022). Technology adoption practices can vary across industries; therefore, it is important to consider the characteristics of the industry in which a firm belongs when examining technology adoption.

Competitive pressures have been identified as a significant determinant in the adoption of technologies by several researchers (Robertson and Gatignon, 1986; Iacovou et al., 1995; Gibbs and Kraemer, 2004; Zhu et al., 2006; Oliveira and Martins, 2009). Oliveira and Martins (2009) define competitive pressure as, "the degree of pressure felt by the firm from its competitors within the industry" (p. 266). Robertson and Gatignon (1986) suggested that competitive pressures from the market and industry can drive technology adoption for firms, as firms in competitive environments are more likely to adopt technologies to improve their operational efficiency and to acquire a competitive advantage. Porter and Millar (1985) sought to better understand why competitive pressures can drive technology adoption and diffusion and found that the introduction of new technologies can lead to changes to industry structure, can alter the rules of competition, provide ways for firms to outdo their industry competitors, and create opportunities for new businesses.

Several researchers have since identified competitive pressures as determinants of significance for adoption of various technologies, such as e-commerce adoption by small businesses in New Zealand (Al-Qirim, 2007), the adoption of Information and Communication Technologies (ICT) in the Swiss business sector (Hollenstein, 2004), website adoption among Portuguese firms (Oliveira and Martins, 2009), and electronic business adoption among European firms (Zhu et al., 2003). In the Canadian context, Ifinedo

(2011) conducted a survey structured by the TOE framework to examine the factors that lead small medium enterprises (SMEs) in Atlantic Canada to either accept or reject internet and e-business technologies (IEBT). External pressures, defined as competitive pressures from industry, suppliers and customers, were significant predictors in the acceptance of IEBT for SMEs. Ifinedo (2011) explains that firms may be more likely to adopt technological innovations in response to adoption among their competitors or due to demands from customers. However, Zhu et al. (2006) found that while competitive pressures positively affect adoption, too much competition intensity can "drive firms to leap rapidly from one innovation to the next without sufficient time to infuse the innovation into the organization" (p. 1571). Therefore, while competitive pressures can positively affect technology adoption, too much competition intensity can have negative implications for firms. Ultimately, the impacts of competitive pressures on technology adoption in the existing literature are unclear.

In addition, the existing research suggests that mature industries are less likely to adopt new technologies. Earlier research suggested that certain industries, such as manufacturing, have less technology demands than industries such as telecommunications (Hsu, 2006), however more recent literature suggests that all industries, including mature industries that are traditionally less technologically demanding, are now becoming more technology intensive (Bademosi and Issa, 2022). Mature industries have experienced rapid advancements in technologies such as automation and robotics that have fundamentally transformed their industries. For example, sensors can monitor important safety metrics such as blood pressure, heart rate and proximity detection (Awolusi et al., 2018). As a result, the literature suggests that industry pressure to adopt technologies is increasing for all industries, including mature and less traditionally technology intensive industries.

Another environmental factor is government regulations, which are considered to have both a positive and negative impact on innovation depending on the direction of policy. For instance, if policy constrains industry, it may have a negative effect on innovation (Baker, 2012). Baker (2012) states that government can effectively mandate innovation through the regulatory environment. For example, in the mining sector, Gao et al. (2019) state that health and safety legislation can slow innovation due to the risks imposed in the testing of a new technology. In contrast, some of the literature suggests that safety legislation has induced technological innovation in mining (Gruenhagen and Parker, 2020). Furthermore, the literature suggests that a lack of government support and legislation can hinder technology adoption for firms. In the context of the agricultural sector, some researchers have studied the barriers to the adoption of blockchain technology and found that a lack of government regulation is a significant barrier to adoption (Yadav et al., 2020). A lack of government regulations can also lead to uncertainty among potential adopters regarding the regulatory environment. In their model, Yadav et al. (2020) found that a lack of government regulation and uncertainty, along with a lack of sufficient trust with external stakeholders, were the most significant barriers to adoption in the Indian agricultural sector. Yadav et al. (2020) note that government support for technology is important because it can increase awareness of the technology among potential adopters and thus encourages adoption.

2.7.4 Summary of Factors of Relevance to this Research

Overall, there are several factors that influence technology adoption decisions for firms cited in the IS literature. Table 3 includes a summary of the factors that are included in this research. For the technology context, factors of relevance include the characteristics of technologies, observability, complexity of the technology (ease of use), relative advantage/perceived benefits, trialability, and compatibility of the technology. In the organizational context, factors of relevance in this research are the formal and informal linking structures within companies, top management support, communication processes, availability of slack resources, and firm size. In the environmental context, factors of relevance include industry characteristics, competitive pressures, market structure, external technology support and infrastructure, and government regulations and support.

Table 3: Technology-Organization-Environment Factors Included in Research

Technology Context	**Organization Context**	**Environment Context**
Technology characteristics	Formal and informal linking structure	Industry Characteristics
Observability	Top management support	Competitive pressures
Complexity of technology (ease of use)	Communication processes	Market structure
Relative advantage/perceived benefits	Availability of slack resources	External technology support and Infrastructure
Trialability (ability to test technology before adoption)	Firm size	Government regulations and support
Compatibility		

Source: Authors Own.

2.7.5 Critique of the TOE Framework

It is important to note that the TOE framework has received a substantial amount of criticism in the literature. According to Dedrick and West (2003), the TOE framework as presented by Tornatzky and Fleischer (1990) is “little more than a taxonomy for categorizing variables and does not represent an integrated conceptual framework or a well-developed theory” (p. 238). As a result, scholars such as Baker (2012) and Gangwar et al. (2014) have suggested that technology adoption at the organizational level would benefit from the development of a more robust organizational framework, with clearly defined constructs. For example, in one study (Zhu and Kraemer. 2005), technology competence was identified as a variable in the technological context for e-business adoption and usage, but in another study on RFID adoption (Rafiquea et al., 2022), technology competence was identified as a variable in the organizational context. The inconsistencies in categorizing the variables across different studies furthers the argument put forth by Low et al. (2011) that the TOE framework fails to explicitly identify the major constructs and variables in the model. To respond to this limitation, Low et al. (2011) suggests that future research should consider combining more than one theoretical model to better understand the technology adoption process.

Additionally, the TOE framework has remained largely undeveloped since it was first introduced. Instead, what has emerged is a lack of clarity with regards to the specific factors that influence adoption. As a result, researchers have modified the TOE framework with specific variables relevant to specific contexts. Zhu et al. (2006) conducted a literature review of studies that use the TOE framework and concluded that the specific measures identified in the technological, organizational, and environmental contexts vary across different studies. According to Parveen (2012) several studies that use the TOE framework have included variables such as external pressure, financial resources availability, vendor support, perceived benefits, and top management support. As a result of the variability in factors pertaining to technology adoption, it was not possible or within the scope of this research to analyze all the factors that have been studied in the literature, and instead the more common factors were selected based on a review of several studies that utilize the TOE framework.

2.7.6 In Defense of the TOE Framework

Despite these criticisms, the TOE framework remains the most cited framework in the technology adoption literature for organizations (Thomas and Yao, 2023). Dedrick and West

(2003) argue that the TOE framework remains “a useful analytical tool for distinguishing between inherent qualities of an innovation itself and the motivations, capabilities, and broader environmental context of adopting organizations” (p. 238). For the purposes of this research, the focus is on technology adoption and not diffusion, which was one of the considerations that was made when selecting the TOE framework over the DOI theory to guide this research. Additionally, the TOE framework is the dominant framework used to study technology adoption at the organization-level because the general categories (technology, organization, environment) allow for a meaningful analysis of individual perceptions and opinions about specific technologies, systems, potential challenges, the impact of the technology on the entire value chain, and organizational capacity to use and integrate a technology (Oliveira and Martins, 2011; Awa et al., 2016). Moreover, as noted by Gruenhagen and Parker (2020) technology adoption is a highly complex process dependent upon the context in which the adoption takes place, and the TOE framework allows the researcher to account for the contextual factors that influence technology adoption decisions (Tornatzky and Fleischer, 1990; Zhu et al., 2006).

2.8 Technology Adoption in the Mining Sector

Much of the literature on technology adoption in the mining industry is grounded in the innovation literature (Gruenhagen and Parker, 2020), and some researchers have incorporated specific theories, such as the DOI (Curran, 2015) and the TOE framework (Ediriweera and Wiewoira, 2021) into their research. Other studies are grounded in the literature on global supply chains (Kiambati, 2019; Caldaza Olvera, 2021), institutions and economic development (Kuan et al., 2015), regional innovation systems (Hall, 2017), ecosystems (Steen et al. 2018), and clusters (Warrian and Mulhern, 2009). In the engineering field, some scholars have conducted case studies on the adoption of specific technologies, such as robotics (Marshall et al. 2016), industrial IoT (Aziz, 2020; Molaei et al., 2020), remote sensing (Loots et al., 2022), battery electric vehicles (Grycan, 2022), drones (Rathore and Kumar, 2015; Shahmoradi et al., 2020), and LTE (Long-Term Evolution) (Conway, 2020).

Existing literature on technology adoption in the context of the mining sector in Canada has focused on the impact of technological advancements on industrial relations (Chaykowski, 2002), the social license to operate (Prno and Solocombe, 2012), the mining innovation system in Greater Sudbury, Ontario (Hall, 2017), the impact of research and development in Canada's mining industry (Warrian, 2020), and the impacts of digitalization on mining communities (Storey, 2022). The more recent literature relevant to technology adoption in the mining sector focuses on the innovation ecosystem (Steen et al., 2018), often through a systems approach (i.e., Regional Innovation Systems) (Hall, 2017) or with a focus on a specific mining innovation cluster (i.e., Warrian and Mulhern, 2009).

Literature on the drivers and barriers to technology adoption in the mining industry is limited (see Steen et al., 2018; Gao et al., 2019; Gruenhagen and Parker, 2020; Ediriweera and Wiewoira, 2021). Of particular relevance to this thesis, Gruenhagen and Parker (2020) conducted a systematic review on the drivers and barriers to innovation adoption in the mining sector and concluded that the existing literature often places too much emphasis on the characteristics of specific technologies, which fails to acknowledge regional factors that impact the innovation process, specifically different government policies and regulations, cultural norms and land settlement processes. In addition, Steen et al. (2018) explored the implications of digital technologies on the mining innovation ecosystem, with comparative analyses on digital technology adoption in the agriculture and aerospace industries. While Gao et al. (2019) analyzed the digital transformation in the mining industry to gain an understanding of the challenges that arise in the adoption of digital technologies, such as IoT. Finally, Ediriweera and Wiewiora (2021) examined the enablers and barriers to technology adoption in the mining industry in Australia with the use of the TOE framework.

The systematic review by Gruenhagen and Parker (2020) also emphasizes that technology adoption is complex, context-specific, and dependent on the interests of the specific stakeholders involved (Gruenhagen and Parker, 2020). As a result, the propensity to adopt technologies by mining companies can be influenced by regional differences. Gruenhagen and Parker (2020) found that 40% of articles on innovation in the mining sector are in the context of Latin America, specifically in Brazil and Chile, while areas of geographical significance to the global mining industry, such as Canada, are underrepresented and neglected in the literature. While the mining industry is a global industry dominated by several multinational mining companies, country-specific institutional, regulatory and policy differences can impact the adoption of technology in the mining sector (Gruenhagen and Parker, 2020).

Gruenhagen and Parker (2020) further note that there was little interest in the academic literature on innovation adoption in the mining sector until 2018, which indicates that the topic is gaining more relevance both in practice and in academic literature. In their analysis, from 1990 to 2017 a maximum of three articles per year were published on technology adoption in the mining industry, while in 2018, nine articles were published on the topic (Gruenhagen and Parker, 2020). Gruenhagen and Parker (2020) state that this indicates that the topic is increasingly relevant among researchers, which correlates with industry perspectives on the increasingly important role of technology in the mining sector (PwC, 2017). Furthermore, while their initial search criteria included 263 articles, upon further analysis only 27 of the articles fit their search criteria. In the context of Canada, only two articles were included in their analysis (specifically Chaykowski, 2002 and Hall, 2017). This suggests a gap in the literature on innovation adoption and particularly in the context of Canada's mining sector.

2.8.1 The Drivers and Barriers to Technology Adoption in the Mining Sector

Through their systematic review, Gruenhagen and Parker (2020) identify several drivers and barriers to technology adoption, as shown in Table 4. The top three drivers to technology adoption identified in their research are to improve health/safety, productivity, and sustainability, while the top three barriers to adoption are identified as investment costs/lack of financial resources, workforce/union resistance, and administrative hurdles due to the centralized structure of mining companies. As demonstrated in Table 4 the existing literature on the drivers and barriers to technology adoption in the mining sector cite a wide variety of factors that influence adoption. They further state that the relative importance of each of the factors varies depending on the context of adoption and the nature of the innovation. As an example, for technologies such as drones and wearables, cognitive impediments or workforce resistance may pose as a more significant barrier than investment costs/lack of financial resources (Gruenhagen and Parker, 2020).

Their review also demonstrates that drivers and barriers to technology adoption in the mining sector arise at different levels, from the firm level to the system/institutional level. Some factors, such as the regulatory environment, can appear as either barriers or drivers depending on the direction of regulations and policies. For example, regulatory requirements can be a driver for technology adoption, while regulatory uncertainty can be a barrier to adoption. At the firm level, a culture of innovation is a driver for adoption while the lack of a culture of innovation is a barrier to adoption. Their review also differentiates between tangible factors, such as productivity or profitability, and intangible factors, such as cognitive impediments or managerial attitudes. Intangible factors are more difficult to address because it requires a shift in mindset which can be difficult to achieve. Additionally, their review revealed both mining-specific and industry-wide general factors that act as drivers and/or barriers to adoption. General factors include R&D spending, government policy, regulatory environment and financial resources, while mining-specific factors include corporate social responsibility and archetypes.

Table 4: Drivers and Barriers to Technology Adoption in the Existing Literature

	Drivers	Barriers
Institutional/Systems Level	Regulatory requirements Government investment Social Systems	Regulatory uncertainties Lack of government incentives Political uncertainties Regulations discouraging innovation
Competitive Environment	Customer commitment Market pressure Entrants with new technology	Uncertainty Market size Dominant design
Archetypes	Demonstration projects Technology champions Site champions	Lack of testing
Stakeholder Interactions	Knowledge spill-overs Exchange of ideas Collaboration Promotion of adoption	Lack of knowledge transmission Information asymmetry Short-term relationships Lack of promotion of diffusion Lack of coordination & networks Lack of trust
Firm	Capabilities Incumbency Human capital Innovation culture Openness to change Entrepreneurial orientation R&D investment Market experience	Lack of capabilities Liability in newness Lack of skilled labour Lack of a culture of innovation Resistance to change Reactive approach Workforce resistance/administrative hurdles
Economic	Reduction in costs (incl. labour) Increase in productivity Increase in efficiency Profitability Minimization of risks	Investment costs/lack of financial resources Low return on investment Risk of failure/investment
Managerial	Facilitators of innovation Management orientation Communication & engagement	Cognitive impediments Short-term mindset Focus on risk avoidance Lack of priority
Operational	Technology obsolescence Improving resource accessibility Changing local conditions	Technological challenges Production pressures Complexity of implementation Geographic isolation
Corporate Social Responsibility	Health and safety Reduction in emissions Sustainability Business ethics Company reputation	

Source: Gruenhagen and Parker, 2020, p. 5).

Gruenhagen and Parker (2020) further note that the ability to test a technology before use, technology champions, site champions, and entrants with new technology can drive technology adoption in the mining industry. Technologies that are proven to offer a reduction in costs and overall industry benefits, such as increased sustainability, are also drivers for technology adoption. In addition, they highlight how an openness to change, R&D investment, market experience and entrepreneurial orientation can have a positive effect on technology adoption. Within a mining operation, Gruenhagen and Parker (2022) note how changing local conditions, improving accessibility to resources and technology obsolescence, which occurs when a current technology is replaced with a more efficient option, can also drive mining companies to adopt technologies. Additional barriers include the remote location of mine sites, firm inertia, high capital intensity, issues with attracting and maintaining the necessary skilled workforce, changing regulatory conditions, and a lack of integration across the mining supply chain (Gruenhagen and Parker, 2020). The mining industry is also prone to lock-in effects of path dependency, where organizational practices and technologies become entrenched, and any disruption to current operations can make it difficult to introduce new practices (Grugenhagen and Parker, 2020; Knobblock and Pettersson, 2010). The level of importance of the factors that influence technology adoption can vary dependent upon the context, which suggests that context-specific research may contribute to a better understanding of technology adoption.

The work of Ediriweera and Wiewoira (2021) is particularly relevant for this thesis. They conducted 28 interviews with mining experts to examine enablers and barriers to technology adoption in the Australian mining sector using the TOE framework. Their results focus on the O and the E[7] and they identify four organizational-level and five environmental-level barriers to adoption, as well as five enablers industry can implement to overcome the identified barriers (Table 5). It is important to note that the work by Ediriweera and Wiewoira (2021) is specific to the Australian context, while similar research on technology adoption in the Canadian mining sector has yet to be conducted which was the catalyst for the research presented in this thesis.

The organizational-level barriers identified by Ediriweera and Wiewoira (2021) include the risks associated with the adoption of unproven technology, limited trust, performance and recognition systems focused on short-term profit, and limited employee involvement in decision making. More specifically, with regards to the risks, Ediriweera and Wiewoira (2021) explain that the adoption of a new technology entails high risk, particularly in the case of unproven technologies. Mine managers may hesitate to adopt unproven technology because it could negatively impact performance. Additionally, experimentation with a new technology may compromise employee safety which is a major concern for mining companies in Australia. In their interviews, disruptive innovations were identified as high risk due to the perceived costs of the technology and the inability to see immediate

[7] Their study does not include technology-level barriers, as the purpose of their research is to explore the culture of innovation in the mining sector in Australia. Additionally, Ediriweera and Wiewoira (2021) state that the existing literature on the drivers and barriers to technology adoption focus on the technology-level while evidence of the organizational and environmental-related factors are limited.

benefits. Furthermore, mines that are operating profitably may view the disruption to operations caused by the adoption of a technology as a significant barrier to adoption.

Table 5: Barriers and Enablers to Technology Adoption in the Mining Sector

Organizational-Level Barriers	• High risk related to the adoption of unproven technology o Limited opportunity to perform differently; Intolerance of risk
	• Lack of trusting relationships o Between mine site and corporate office employees; and between mine site employees and management
	• Performance and recognition systems focused on efficiency and short-term gains o Focus on efficiency and short-term outcomes; Volumetric, compartmentalized approach to KPIs
	• Limited employee involvement in decision-making o Top-down approach to decision making
Environmental-Level Barriers	• Cyclical nature of the mining sector o Commodity prices, market cycles, uncertainty in the market for mineral products
	• Inadequate engagement with external stakeholders o Too focused on shareholders; Limited engagement with external stakeholders in co-creating solutions
	• Geographically dispersed structure o Distance between mine site and head office
	• Capital-intensive nature of the mining sector o Capital driven industry; short-term focus on investment
	• Uncertainty on the ground, operations and market
Enablers to Technology Adoption	• Learning Culture
	• Cross-disciplinary knowledge-sharing
	• External stakeholder engagement
	• Rewards and recognition for innovation
	• Employee empowerment

Source: Adapted from Ediriweera and Wiewoira (2021, p. 5).

Turning to trust, Ediriweera and Wiewoira's (2021) findings suggest that limited trust can exist between mine site employees and head offices as well as between management and employees. As the mining sector is highly cyclical, in downturns or busts employees are often laid off, which can limit the ability to build trusting relationships. Additionally, the centralization of the organizational structure further impedes the ability to build trusting relationships between mine site employees, particularly in large mining companies. The geographical dispersion between mine site employees, who are often located in remote or rural areas versus in a head office which are often located in more urban areas is an additional organizational barrier to technology adoption (Hall, 2017). Similarly, Steen et al. (2018) identify institutional and communication silos between working units as barriers to innovation in mining. As a result, collaboration and the ability to co-create solutions among working units in a mining company is limited. Another organizational-level barrier to adoption identified by Ediriweera and Wiewoira (2021) is limited involvement of employees in decision-making. The organizational structure of mining companies is hierarchical and technology adoption decisions are made by head office employees that are geographically separated from the mine site. This also means that the individuals who decide which technologies to adopt are often separated physically from the implementation process.

Ediriweera and Wiewiora (2021) also found that key performance indicators (KPIs) in the mining industry focus on short term gains, volumetric productivity and efficiency, meaning that employees are rewarded for improvements in efficiency, rather than for their degree of involvement in the technology adoption process. More specifically, they argue that “the lack of recognition for employee contributions towards innovation significantly impedes the technology adoption possibilities in mining since innovation outcomes are not aligned with existing KPIs” (p. 8). The adoption of new technologies inevitably causes disruption to mining operations which can negatively affect short-term production targets and adversely impact the performance indicators of employees. As a result, employees have little incentive to participate in technology adoption processes. Steen et al. (2018) also suggest that existing KPIs can act as barriers to innovation in mining. Both Ediriweera and Wiewiora (2021) and Steen et al. (2018) suggest that incentive structures to encourage innovation of the entire mining system may be more conducive to innovation than the current KPI structure that is focused solely on individualized daily volumetric production.

In terms of the environmental-level barriers discussed by Ediriweera and Wiewoira (2021), they discuss the cyclical nature of the mining sector, uncertainty in operations and the market, the capital-intensive nature of the mining sector, inadequate engagement with external stakeholders, and a geographically dispersed structure (i.e., distance between mine site and head office). More specifically, mineral commodity prices are driven by the global supply and demand cycle, which is highly cyclical and volatile in nature (Calzada Olvera, 2022; Fernandez, 2020). Whether mining companies engage in innovation is dependent on the market dynamics of global commodity prices (Steen et al., 2018; Ediriweera and Wiewoira et al., 2021). The cyclical nature of the market creates challenges to technology adoption, such as limited time to innovate, risk aversion, and prioritizing productivity and efficiency over the long-term investments required to innovate (Ediriweera and Wiewoira, 2021). The cyclical nature of the mining sector can adversely impact relationships with suppliers due to the shifting dynamics that often take place during the booms and busts of the economic cycle. During economic booms, mining companies are often more collaborative with suppliers on technology development, while suppliers respond by increasing their prices due to a rise in demand. During economic busts, mining companies reduce investments in technology development, resulting in a reduction in demand for suppliers (Ediriweera and Wiewoira, 2021).

The high capital-intensive nature of the mining industry has been attributed to the development of a risk-averse culture with respect to technology adoption and innovation (Lay et al., 2022). In the context of the Australian mining sector, barriers to adoption in the environmental context include a focus on productivity, satisfying shareholders, inadequate engagement with external stakeholders, negative attitudes towards research institutions, and the geographical distance between mine sites and head offices, discussed in more detail below (Ediriweera and Wiewoira, 2021).

As Ediriweera and Wiewoira (2021) argue, mining companies in Australia prioritize productivity and maximizing shareholder dividends, which can take precedence over the adoption of new technologies. They further identified inadequate engagement with external stakeholders as an environmental-level barrier to technology adoption. More specifically, they argue that mining companies tend to keep innovations to themselves rather than share with other industry stakeholders, which limits their ability to collaborate in co-creating new technology solutions. In addition, their interviews reveal that mining companies tend to have a negative attitude towards research institutions and are hesitant to trust the abilities of research centres. They also suggest that mining companies often fail to establish adequate communication with suppliers, which means that suppliers may not have the necessary information required to develop the solutions desired by the mining company. Finally, Ediriweera and Wiewoira (2021) identify the geographic dispersion of mine sites and head offices as the final environmental-level barrier to technology adoption. Mine sites are most often located in rural and remote areas, while corporate activities tend to be located in urban areas. The distance between the mine site and head office can limit coordination efforts, knowledge and information sharing, and impedes access to resources.

Ediriweera and Wiewoira (2021) research also identifies a number of enablers of technology adoption including, a learning culture, cross-disciplinary knowledge sharing, external stakeholder for engagement, rewards and recognition for innovation, and employee empowerment. A learning culture enables experimentation with new technologies and the testing of new technologies which is necessary for successful technology adoption. Their research recommends mining-specific test sites to enable a learning culture in the mining sector, where potential failures are seen as a necessity to successful technology adoption. Cross-disciplinary knowledge sharing can strengthen technology adoption efforts by encouraging different work units to collaborate on identifying solutions. Engagement with external stakeholders through knowledge sharing and collaboration is also an important enabler to technology adoption, which can enable risk sharing and trust among stakeholders. Rewards and recognition systems for innovation can also enable adoption. As mentioned, the

KPI system focuses on individual contributions to short-term, daily volumetric production rather than a more holistic view of the whole system. Ediriweera and Wiewiora (2021) recommend the implementation of a combined KPI system where employees are recognized for innovation-driven behaviours that encourage technology adoption to support the development of an innovative culture. Finally, Ediriweera and Wiewiora (2021) identify employee empowerment as an enabler for innovation, where employees are given the autonomy to identify their own solutions to exiting challenges.

2.9 Conclusion

The benefits and implications of technology adoption on the economy and society have been studied extensively. As demonstrated, the literature on technology adoption is highly fragmented across disciplines, with several different theories and models developed to better understand, explain, and predict technology adoption at the individual and organization level. Technology adoption has been most commonly studied at the individual level; however, researchers have noted that technology adoption at the organizational level is more complex, convoluted and challenging due to the different interests and stakeholders involved in the decision-making process. The vast number of models and theories may also indicate that the phenomenon of technology adoption at the organizational level is not fully understood by researchers. However, the TOE framework enables the researcher to approach the subject of technology adoption from a multi-level perspective to gain a better understanding of the factors that impact technology adoption.

With regards to the mining sector, the existing literature demonstrates that drivers and barriers to technology adoption can be both mining specific and affect other industries. However, the prevalence of mining-specific factors influencing technology adoption, such as the need to test technologies before adoption, require context specific research. Additionally, the literature on the drivers and barriers to technology adoption in the mining sector suggests that the factors that impact technology adoption require a multi-level framework to gain a holistic view of the subject. While the mining-specific research in the context of Australia creates a better understanding of the drivers and barriers to technology adoption, there is a need to conduct research specific to the Canadian context due to the existing gap in the literature.

Chapter 3: Methodology and Methods

3.1 Introduction

Chapter 3 provides an overview of the methodology to respond to the following research questions:

1) What technologies are being adopted in the mining sector in Canada?
2) What is driving the adoption of these technologies?
3) What factors are barriers to the adoption of new technologies?
4) What factors are enablers to the adoption of new technologies?

First, this chapter will provide an overview of the research worldview and methods, followed by a justification for the use of a survey approach, characterized by quantitative and qualitative questions where respondents can provide in-depth responses. Next, Chapter 3 provides a brief overview of the survey design, specifically a description of the methods used to collect and analyze the data.

3.2 Research Paradigm

In the social sciences, a "paradigm" refers to the underlying philosophical assumptions and beliefs that distinguishes the worldview of the researcher, which are then used as tools to respond to the research questions (Kaushik and Walsh, 2019; Denzin and Lincoln et al., 2011). In other words, a paradigm defines the reality of the researcher, and is shaped by unique ontology and epistemology (Creswell, 2009; Guba, 1990). This research is embedded in the pragmatist paradigm, where researchers are encouraged to utilize all available methods to answer their research questions, whether qualitative or quantitative (Kaushik and Walsh, 2019). Glasgow (2013) states that the pragmatic research approach is useful in “guiding action in real-world settings” (p. 260). Ultimately, the purpose of a pragmatic paradigm is to “produce results that are relevant to stakeholders” with a specific focus on context, application, and practice (Glasgow, 2013, p. 257). Central to the pragmatic paradigm is the openness to utilize whichever methods enable the researcher to best answer their research question.

Important tenets of the pragmatic worldview as defined by Murphy and Murphy (1990), Cherryholmes (1992) and Creswell (2016) include: researchers have the freedom to choose the methods and procedures of research that are most suitable for the specific context and purpose of research; research is highly contextual (i.e. social, political, historical contexts); pragmatists base their research on its intended consequences; researchers do not have to commit to one reality; it is less concerned with the methods of choice, and instead focuses on the research problem and research questions (Creswell, 2016, p. 23). Given these tenets, the pragmatic paradigm is most suitable for this research and aligns best with my worldview as a researcher. Approaching research with a pragmatic worldview enables the researcher to maintain a certain degree of openness with their methodology and to the outcomes of the research, which can then be used to guide future research. The purpose of pragmatic research is to analyze the consequences of actions, rather than to combine methodologies.

3.3 Research Methodology

As mentioned, this research utilizes a survey approach to explore the drivers and barriers to technology adoption in Canada's mining sector. Surveys are suitable to explore various aspects of a given research problem, or to explain trends in the data (Sitzia, 2003; Creswell, 2012, p. 376). As defined by Bhattacherjee (2012), survey research entails "the use of standardized questionnaires or interviews to collect data about people and their preferences, thoughts, and behaviors in a systematic manner" (p. 73). A survey approach is particularly useful to collect "unobservable data" on the preferences, beliefs, attitudes, and factual information (i.e., in the context of this research, size of company) of a specific population (Bhattacherjee, 2012, p.73). Additionally, a survey approach is suitable for remotely collecting data, such as via email (Bhattacherjee, 2012). Due to the time constraints of a master's thesis, a questionnaire or survey approach is also well suited for its ability to collect a significant amount of data in a short period of time, which can assist the researcher "in planning and delivering end results" (Sitzia, 2003, p. 262). In addition, survey research is useful in collecting data from business organizations, particularly with respect to issues within organizations (Malhotra and Grover, 1998).

This research is also exploratory, a type of research that is particularly useful as a starting point for under-researched areas or to gain familiarity with a specific research problem (Malhotra and Grover, 1998). The exploratory study provides the researcher with the ability to create innovative ideas and maximize creativity, as well as to potentially identify new areas for research. The goals of exploratory research are: "to scope out the magnitude or extent of a particular phenomenon, problem, or behavior, (2) to generate some initial ideas (or "hunches") about that phenomenon, or (3) to test the feasibility of undertaking a more extensive study regarding that phenomenon" (Bhattacherjee, 2012, p. 6). As discussed in Chapter 2, research on the drivers and barriers to technology adoption in the mining sector is limited, even more so in the context of Canada (Gruenhagen and Parker, 2020). For example, in their systematic review, Gruenhagen and Parker (2020) only identify two articles in the Canadian context that address the drivers and barriers to innovation adoption in mining in Canada, specifically Chaykowski (2002) and Hall (2017). In this context, an exploratory study is suitable to gain a general understanding of the drivers to adopt technology and the barriers faced by mining companies from the perspectives of mining industry stakeholders, and to potentially inform future research in the fields of technology adoption and innovation with exploratory or descriptive studies.

3.4 Survey Design

As mentioned, this research utilizes a survey approach through the deployment of a cross-sectional survey, where data is collected at one point in time (Creswell, 2009). A cross-sectional research approach was selected primarily due to limited accessibility to potential participants and the time constraints of a master's thesis. The survey includes both multiple choice, scalable, open-ended questions, and closed-ended questions. Closed-ended questions have pre-set response options created by the researcher which allows the researcher to compare responses. In addition, closed-ended questions can be coded numerically to allow for statistical analyses (Creswell, 2009). An example of a closed-ended question included in this research pertains to company size, as detailed below:

Q. How many employees does your company employ in Canada? (Check one)

a) 1-99

b) 100-499

c) >500

d) Unsure[8]

The open-ended questions, in contrast, allow the researcher to inquire further about a specific aspect of the research question without providing the participants with pre-set responses. For instance, this research asked the closed-ended question, “Has technology adoption increased in the past five years?” with the pre-set responses yes/no. For individuals who responded yes, participants were provided with the follow up, open-ended question, “Why has technology adoption increased in the last five years?” Open-ended questions enable respondents to provide the researcher with information shaped through their experience, without influence from the researcher’s worldview (Creswell, 2009). Open-ended questions are also suitable for research questions with limited existing explanations in the literature. As a result, this research combines both open and closed-ended questions due to the strengths of combining both approaches to identify trends across the drivers and barriers to technology adoption in the mining sector.

The survey questions where informed by a review of relevant literature on the TOE framework, technology adoption, and the mining sector. More specifically, the survey

[8] These numbers were obtained from Statistics Canada, where small companies are considered to have fewer than 100 employees, medium companies have 100-499 employees while large companies have more than 500 employees (Statistics Canada, 2022).

questions for the technology context were informed by several studies that utilize the TOE framework to analyze enablers and barriers to technology adoption at the firm-level. As discussed by Rogers (2003), factors that impact technology diffusion include relative advantage, complexity, compatibility, ease of use, trialability and observability, which are also often incorporated in studies that utilize the TOE framework. For the technology enablers, factors included in this survey are ease of use of the technology, compatibility of the technology with existing operations, skills and expertise of employees, skills and expertise of management, knowledge of the technology by workers, knowledge of the technology by management, ability to test the technology before adoption, and proven track record of the technology in a mining environment. Technology barriers included the cost of the technology and its implementation; issues with network connectivity; difficulty integrating new technology into existing operating/production systems; lack of skills and expertise among management and workers; a lack of knowledge of the technology among management and workers; lack of underground testing of technology in a mining environment; and lack of external technology maintenance and support services (Table 6).

Table 6: Technology Factors

Technology Enablers	Technology Barriers
Ease of use	Cost (of technology and implementation)
Reliability and durability of the technology in a mining environment	Issues with network connectivity
In-house employee technological skills/expertise and/or knowledge of the technology	Difficulty integrating new technology into existing operating/production systems
Compatibility with existing operating/production systems	Technology is not suitable to solve existing challenges
Ability to test technology before adoption	Lack of in-house employee technological skills/expertise and/or knowledge of the technology
Proven track record of the technology underground/in a mining environment (e.g., at another mine site or test mine)	Lack of in-house management technological skills/expertise and/or knowledge of the technology
	Technology has not been tested/used underground or in a mining environment
	Lack of external technology-related service and maintenance support available locally/regionally (e.g., from mining supply and services companies)

Source: Based on the findings by Tornatzky and Fleischer (1990), Rogers (2003) and Ediriweera and Wiewoira (2021).

The questions for the organizational and environmental contexts were largely informed by the research conducted by Ediriweera and Wiewoira (2021) on the enablers and barriers to technology adoption in the mining sector in Australia, where the TOE framework was utilized to guide their interview questions with mining stakeholders. As discussed in Chapter 2, the purpose of the work by Ediriweera and Wiewoira (2021) was to better understand how organizational culture in the context of Australia's mining sector impacts technology adoption. Ediriweera and Wiewoira (2021) identify a learning culture, rewards and recognition for innovation, and employee empowerment as enablers in the organizational context for technology adoption in the Australian mining sector Environmental enablers include cross-disciplinary knowledge sharing and external stakeholder engagement. Their research focused on the organizational and environmental contexts, whereas this research also includes an analysis of the technological context. This research included these variables to identify whether the same factors impact technology adoption in the Canadian context (Table 7 and Table 8).

Table 7: Organizational Factors

Organization Enablers	Organization Barriers
Leadership that promotes innovation	High risk in the adoption of unproven technology
Corporate culture that emphasizes creativity and learning	Inability to see immediate results from the technology
Access to internal capital (e.g., slack resources)	Limited internal capital (e.g., slack resources)
Open communication and knowledge sharing within organization	Limited communication between mine site and corporate offices
KPIs that recognize system in its entirety, rather than a single production unit	KPIs focused on productivity of single production unit
Employee willingness to learn and use new technology	Employee/union concerns over job losses or changes in type of work
Employee autonomy	Fragmented access to information within mining company
Rewards and recognition for innovation	Limited trust between mine site and head offices

Employee involvement in decision making	Limited employee involvement in decision making

Source: Based on the findings by Tornatzky and Fleischer (1990) and Ediriweera and Wiewoira (2021).

Table 8: Environmental Factors

Environment Enablers	Environment Barriers
Competitive pressures	High capital intensity
Knowledge sharing between mining company and external stakeholders	Insufficient communication with external stakeholders in co-creating solutions
Compliance with provincial and/or federal government regulations	Government regulations
Government support and/or funding	Lack of government funding/support
Existing local labour force skills and expertise	Cyclical nature of the mining industry
Trusting relationships and collaboration with external stakeholders	Uncertainty about mineral deposits underground
Geographic proximity between mine sites and head offices	Industry health and safety standards
Geographic proximity between mine sites and R&D facilities	Limited engagement with external stakeholders

Source: Based on the findings by Tornatzky and Fleischer (1990) and Ediriweera and Wiewoira (2021).

Respondents were also asked to identify the top three technologies adopted in the mining sector in the last five years. The technology types selected for this research were informed by the findings from our systematic review of the *Canadian Mining Journal* (CMJ) on technology adoption in Canada's mining sector (Crabbe et al., forthcoming) and based on interviews from the *Remote Controlled*, national research project led by Dr. Heather Hall.[9] For the systematic review[10], the technology types were selected based on an initial review of industry reports and a review of the academic literature. For the *Remote-Controlled* research study, participants were asked to identify the top three technologies being adopted in the mining sector in the last five years, and the top three technologies that will be adopted in the next five years. Based on a review of the interviews, connectivity, LTE and Wi-Fi, as well as mapping of geospatial data and for visualization were included in this survey. The technologies included in this survey are battery electric vehicles; sensors on equipment (e.g., to detect hazards, improve safety, etc.); connectivity, 5G, LTE; drones; mapping (e.g., geospatial data and visualization); artificial intelligence; new ventilation, autonomous operations, and RFID wearable sensors.

3.5 Sources of Data and Methods of Data Collection

This survey was sent to mining industry stakeholders, specifically mining company representatives, mining technology supplier representatives, government, non-profit organization representatives, and mining industry association representatives. This research is also specific to the Canadian context, meaning that all research participants were required to be representatives of companies or organizations located in Canada, excluding Nunavut and NWT due to the requirement to obtain a research license and the time available to do so.

[9] For more information, please visit the Remote Controlled Mining website.

[10] The technologies included in the systematic review were virtual reality, internet of things, electric vehicles, artificial intelligence, autonomous, digital mine, sensors, software, machine learning, robot, drone. The top three technologies being adopted in the mining sector according to our review of the CMJ are sensors, battery electric vehicles and artificial intelligence.

Importantly, participants in this research remained entirely anonymous. Existing research suggests that anonymous surveys encourage a greater level of disclosure of sensitive information than non-anonymous survey methods (Murdoch et al., 2014). Privacy measures were put in place through Qualtrics to disable the tracking of IP addresses, and none of the questions included in the survey required participants to identify themselves. Instead, participants were asked to categorize themselves as either a mining company representative, mining supply and services company representative, non-profit mining organization representative, government representative, or technology company representative. This research was reviewed and received ethics clearance through the University of Waterloo Research Ethics Board (REB# 44089).

The survey was first launched on June 5th, 2022, in conjunction with the timing of the Prospectors and Developers Association of Canada (PDAC) conference, which is a non-profit organization in Toronto, Ontario and represents mineral exploration and development stakeholders (PDAC, 2023). I also attended the conference and focused my time in the showcase room on Canadian mineral and mining activity where I obtained contact information from potential participants and followed up via email with an invitation to participate in the survey. A “QR” code was also created and added to a poster, which was placed at the MineConnect booth in the Northern Ontario Mining Showcase area for the duration of the conference. The QR code was also handed out to individuals at the conference.

Industry Associations, such as the Canadian Institute of Mining (CIM), MineConnect, Ontario Mining Association (OMA), the Canadian Mining Association (CMA), and the Mining Industry and Human Resources Council (MiHR) were contacted to distribute the survey to their members. CIM, OMA and MineConnect included the survey in their September 2022 newsletters, which were shared with their membership base consisting of mining sector professionals and stakeholders (CIM, 2023). Invitations to participate in the survey were also sent to participants in the national “Remote Controlled” research project led by Dr. Heather Hall. Following this initial wave of invitations, the researcher obtained an amendment to their ethics application to allow for “reminder” emails to be sent to the same group of potential participants in hopes of increasing the survey response rate. A total of 41 people responded to the survey, however, only 39 surveys were completed and included in this research.

3.5.1 Respondents

As noted, respondents were asked to identify their organization type as either a mining company, mining supply and services (MSS) company, non-profit mining industry organization, technology company, government, and ‘other.’ Respondents were asked to identify their organization type to better understand the perspectives and viewpoints of participants from their role in the mining sector. As seen in Table 9, survey results indicate that of the 39 responses, most respondents identified as representatives of a mining company (34.2%) or MSS company (23.7%). Insights from representatives of mining companies and

MSS companies can lead to a better understanding of the motivations behind technology adoption from industry stakeholders who are engaged in and familiar with the industry.

Table 9: Type of Organization Identified by Respondents

Organization Type	Percent of Respondents (%)
Mining company	34.2
Mining supply and services company	23.7
Non-profit mining industry organization	18.4
Technology company	13.2
Other	7.9
Government	2.6

Source: Authors' Own.

As mentioned in Chapter 2, for research on technology adoption in the Canadian context it is important to identify the geographical dispersion of responses due to the regional variation that exists in industry and technology needs across Canada's provinces and territories. Table 10 represents the geographical dispersion of respondents, which demonstrates that 87.2% of respondents to this survey are representatives of companies or organizations with operations in Ontario. As a result, no geographic differences were identified in the findings of this research, as responses were heavily skewed towards Ontario. Operations were, however, identified in each of the jurisdictions included in this research. 25.7% of respondents reported having operations located in British Columbia, while 22.9% of respondents have operations in Quebec. It is also important to note that respondents were able to select more than one response to account for companies or organizations with operations in more than one province.

Table 10: Geographic Dispersion of Respondents

Province	Percent of Respondents (%)
Ontario	87.2
British Columbia	25.7
Quebec	22.9
Newfoundland and Labrador	17.1
Manitoba	15.4
Saskatchewan	10.3
Yukon	7.7
Alberta	7.7
Prince Edward Island	2.6
Nova Scotia	2.6
New Brunswick	2.6

*Respondents could select more than one response.

Source: Authors Own.

3.6 Data Analysis

The survey was imported into Excel which was then used to analyze the data. The first step was to clean up the data by removing rows and columns with unnecessary information, such as the computer-generated number associated with each respondent. I then analyzed each response and removed survey responses with incomplete data. All respondents were required to consent to their participation in the survey before gaining access to the survey, therefore all responses collected consented to participate in the survey. I then re-labeled all respondents and shortened survey questions to improve readability of the data. Responses to questions in the technology, organizational and environmental contexts were separated into different tabs to analyze drivers and barriers specific to each context in more detail. It is important to note that the data produced by Qualtrics for the multiple-choice questions where respondents could select up to three responses were recalculated as the initial data report produced by the survey software was inaccurate and did not account for the fact that respondents could select up to three responses. Once the data had been recalculated, I focused on the TOE-related questions and created figures to visualize the data. For the open-ended questions, qualitative responses were analyzed and coded by generic themes (i.e., reduce costs). Important quotations were highlighted for further analysis on potential trends across responses. For the Likert-scale questions, descriptive statistics were calculated on the means to identify the average responses across participants.

3.7 Limitations

There are also several limitations to survey research that may impact the validity of these results. This survey research is impacted by non-response bias, sampling bias, social desirability bias, and common method bias. Non-response bias is common in survey research where response rates range from 15-20 percent (Bhattacherjee, 2012). The small sample size of 39 respondents to this survey means that the results are not statistically relevant or generalizable, however they do provide a window into technology adoption in the Canadian mining sector that can inform future research. While non-response bias was accounted for by the researcher with an Ethics amendment to include a reminder email to complete the survey, the response rate remained low. Another limitation that impacts this research is sampling bias, due to the nature of online survey research where respondents require access to Internet to complete the survey. As a result, this survey excluded those without Internet access, which can be particularly limiting for research in the mining sector where mine sites are often located in rural, remote, and isolated regions with limited internet access. As a result, this research may have been less accessible to individuals in rural and remote areas in Canada.

Additionally, sampling bias may impact these results particularly in the organizational context, as company representatives targeted in this survey (i.e., CEO's) may be unaware of the organizational challenges at the operator or worker level that create barriers to technology adoption. The social desirability bias (SDB) occurs in instances where respondents curate their survey responses in a socially desirable way (Roxas and Lindsay, 2012). The SDB is a critical issue for survey research in sustainability and environmental management as company representatives can overstate the importance of sustainability, curate responses in ways that favour their company and understate their challenges (Roxas and Lindsay, 2012). Lastly, common method bias can occur with cross-sectional surveys because all the data is collected at one point in time. This survey may have left out important variables that impact technology adoption in the Canadian mining sector. For instance, firm characteristics identified by Gruenhagen and Parker (2020) such as entrepreneurial orientation, market experience, R&D investment, and openness to change were not included in this survey which may impact the validity of the results. Despite these limitations, the results of this exploratory research are one piece of a larger study on technology adoption in the mining sector and can be used to inform future research on the subject.

3.8 Conclusions

This chapter provided an overview of the methodology used to guide this research. As discussed, this research is guided by the pragmatic research paradigm, which is particularly useful in new research areas and allows the researcher to use all available methods, whether qualitative or quantitative, to answer the research questions. This survey is exploratory in nature to gain insight into Canada's mining sector. Next, this chapter provided an overview of the research design, which was a cross-sectional survey informed by the TOE framework. The survey included descriptive, quantitative questions and open-ended qualitative questions where respondents could provide more detail in their responses. This chapter then discussed the methods of data collection, which consisted of an online survey through Qualtrics. Respondents consisted of mining company representatives (34.2%) and mining supply and services company representatives (23.7%), non-profit mining industry organizations (18.4%), technology company representatives (13.2%), 'other' (7.9%), and government representatives (2.6%), while the majority of respondents (87.2%) had operations located in Ontario. The chapter concluded with a brief overview of the data analysis methods used to better understand the data.

Chapter 4: Results

4.1 Introduction

This chapter presents the results from the survey that was designed to explore the drivers and barriers to technology adoption in the mining sector in Canada. As described in previous chapters, the survey was developed using the TOE framework, where potential drivers, enablers and barriers are identified and assessed to better understand the specific technology, organizational, and environmental factors that either drive, enable, or act as a barrier to technology adoption. This chapter begins with findings related to the technologies being adopted and technology procurement. Following this, is a discussion on the drivers to technology adoption. Then, findings on the technology, organization, and environment-related enablers and barriers to technology adoption are presented. This chapter concludes with the survey findings on the importance of the ability to test a technology, coordination with external stakeholders, and sustainability for technology adoption in the Canadian mining sector.

4.2 Technologies and Technology Procurement

The following section summarizes the results for a series of general questions regarding the top three technologies that have been adopted in the last five years, as well as how technologies are acquired (i.e., purchased externally or developed in-house) and where technologies are acquired. As noted in Chapters 1 & 2, little is known about the types of technologies being adopted in Canadian mining sector.

4.2.1 Top Technologies and Procurement

Respondents were asked to select the top three technologies being adopted by mining companies in Canada over the last 5 years. As seen in Table 11, the top responses were battery electric vehicles (53.9%), autonomous equipment (46.2%), and sensors on equipment (35.9%). Similar findings were identified in a systematic scoping review of the *Canadian Mining Journal* (CMJ) on the top technologies being adopted by the mining sector in Canada from 2016-2021, where sensors and battery electric vehicles were also identified as top the technologies being adopted by Canadian mining companies (Crabbe et al. forthcoming). Interestingly, artificial intelligence was identified in the systematic review as the third most discussed technology, however artificial intelligence was only selected by 18% of respondents in this survey. It is important to note that the technology types and sources of data were different for this survey to the systematic review, which may explain the variation. For instance, the systematic review did not include connectivity, LTE or Wi-Fi; new ventilation; or mapping. However, these technologies were discussed in our interviews with industry experts for the *Remote-Controlled* project.

Table 11: Top Technologies Adopted by Mining Companies in the Last 5 Years

Technology Type	Percent of Respondents (%)
Battery Electric Vehicles	53.9
Autonomous equipment	46.2
Sensors on equipment (e.g., to detect hazards, improve safety, etc.)	35.9
Connectivity, 5G, LTE	33.3
Drones	25.6
Mapping (e.g., geospatial data and visualization)	23.1
Artificial Intelligence (e.g., use of data and analytics to improve decision making and safety)	18.0
New ventilation	12.8
Autonomous operations	12.8
RFID wearable sensors	10.3
Other: Please specify	7.7

*Respondents could select up to three technologies.

Source: Authors' Calculations.

As discussed in Chapter 2, the literature on mining innovation often argues that mining companies are primarily consumers of innovation and rely heavily on technology suppliers to develop new technologies (Steen et al., 2018; Gruenhagen and Parker, 2020). To investigate this in the Canadian context, respondents were asked *how* new technologies are acquired by mining companies in Canada (Table 12). Overall, 55.3% of respondents indicated that technologies are purchased externally, while 26.3% indicated that technologies are co-developed in-house with external partner(s) (e.g., mining supply and services company, researcher, researcher institute). An additional 7.9% of respondents suggested that technologies are developed in-house, while 7.9% were unsure.

Table 12: How Technologies are Acquired in the Canadian Mining Sector

How Technologies are Acquired	Percent of Respondents (%)
Purchased externally	55.3
Co-developed in-house with external partners	26.3
Developed in-house	7.9
Unsure	7.9

Source: Authors' Calculations.

Respondents were then asked *where* technologies are acquired, specifically internationally, nationally, provincially, or locally (within 100km of mine site). As discussed in Chapter 2, mining companies primarily outsource their technology (Steen et al., 2018). Canada has a highly developed mining services and supply sector with over 4000 companies providing technology, engineering, geotechnical, financial, and other services to mining companies (Government of Canada, 2021). In the Greater Sudbury area alone, there are nine operating mines, and 300 supply and services companies (Greater Sudbury Economic Development, 2023). As seen in Table 13, exactly half (50%) of the respondents stated that technologies are acquired internationally, 42.1% indicated that technologies are acquired nationally, while 5.3% stated that technologies are acquired provincially and an additional

2.6% noted that technologies are acquired locally (within 100km of the mine-site). The reliance of technologies being acquired internationally could be related to the international ownership of mining companies in Canada. However, more research is needed to determine the exact factors.

Table 13: Where Technologies are Acquired in the Canadian Mining Sector

Where Technologies are Acquired	Percent of Respondents (%)
Internationally	50.0
Nationally	42.1
Provincially	5.3
Locally (within 100km of mine site)	2.6

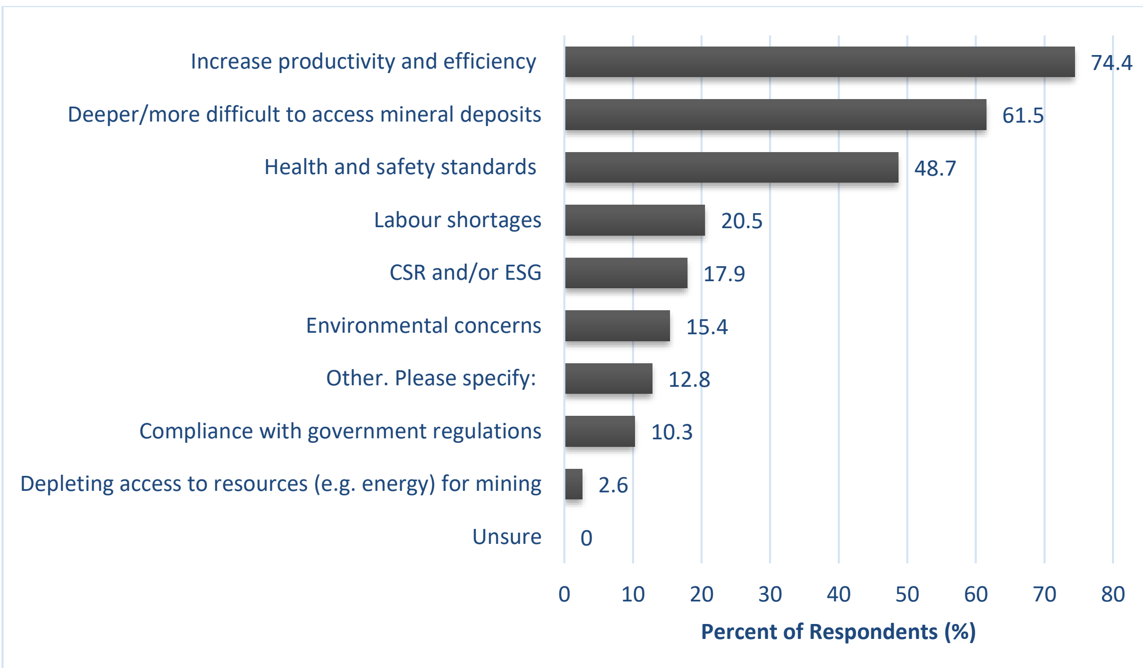
Source: *Authors' Calculations.*

4.3 Drivers for Technology Adoption

To better understand technology adoption in the Canadian mining sector, respondents were asked to identify their top three drivers among a list of drivers commonly discussed in the literature. Figure 2 shows responses to the question asking respondents to identify their top three drivers for technology adoption in the Canadian mining sector. Of note, all the drivers listed were selected as top drivers for technology adoption by at least one respondent, suggesting that there are a multitude of factors driving technology adoption by mining companies in Canada. As Gruenhagen and Parker (2020) argue, technology adoption in the mining sector is highly complex, where the "relative importance" of each driver varies depending upon the context of adoption and the specific interests of stakeholders

(Gruenhagen and Parker, 2020, p. 5). As such, there are many competing factors driving mining companies in Canada to adopt technologies, and the importance of each driver varies among respondents. Nonetheless, several key themes were identified, and are discussed in more detail below.

Figure 2: General Drivers for Technology Adoption in Mining



*Respondents could select up to three drivers.
Source: Authors Own.

As noted in Chapter 2, firms are driven to adopt technologies that improve their productivity and efficiency. Figure 2 shows that 74.4% of respondents identified ‘increase productivity and efficiency’ among the top reasons for technology adoption by mining companies in Canada. Similar findings were identified by Gruenhagen and Parker (2020), where increases in productivity and efficiency were among the top drivers to adopt technology discussed in their systematic review of the innovation and management literature. For instance, in the mining sector, autonomous haulage systems have improved productivity by enabling continuous operations, reducing layover time, and increasing efficiency and production per hour (Hyder et al., 2019). As stated by Steen et al. (2018), “one thing that is clear about economic development is that sustainable improvements in productivity come from technical change” (p. 3). Productivity and efficiency improvements can thus be understood as economic drivers for technology adoption, or as the ‘perceived benefits’ of adoption, as described by Rogers (2003).

It has also been reported that productivity in the sector is expected to decline over the long term due to the depletion of high quality and shallow resource deposits (Syed et al., 2013; Steen et al., 2018; McKinsey & Company, 2022). Thus, in addition to productivity challenges, the mining sector is faced with rising input and production costs due to the depletion of easy-to-access, high grade mineral deposits (Steen et al., 2018). The results suggest that mining companies are driven to adopt new technologies to respond to industry-specific challenges, such as mining at depth. More specifically, Figure 2 shows that 61.5% of respondents selected increasingly deeper and more difficult to access mineral deposits as a driver for technology adoption. As highlighted in earlier chapters, technological innovations can help the sector respond to such challenges as deeper mines and difficulty accessing mineral deposits (Ediriweera and Wiewoira, 2021).

The third top driver, selected by 48.7% of respondents, was health and safety standards. As discussed in Chapter 2, while some researchers have suggested that health and safety standards can act as potential barriers to technology adoption in the mining sector (Gao et al., 2019), the systematic review by Gruenhagen and Parker (2020) revealed that improvements in health/safety are the most discussed driver for technology adoption in the literature. Due to the hazardous nature of mining, the industry faces increased pressures for continuous safety improvements, and industry standards can encourage firms to adopt technologies such as drones and autonomous vehicles that can improve safety and remove workers from hazardous environments.

A smaller proportion of respondents selected labour shortages (20.5%); CSR and/or ESG (17.9%); environmental concerns (15.4%) and compliance with government regulations (10.3%) among their top three drivers for technology adoption. Overall, results show some variance from the systematic review by Gruenhagen and Parker (2020), where it was found that the top drivers discussed in the literature are health and safety improvements, to increase productivity, and sustainability. While health, safety, and productivity improvements appear as top drivers in both the literature and survey results, respondents to the survey appear less driven by ESG/CSR (17.9%) and environmental concerns (15.4%) than what is discussed in the literature. More specifically, when presented with the option to select only three drivers, economic considerations (i.e., productivity/efficiency) and accessing mineral deposits were prioritized over environmental concerns. Future research is needed to explore this in more detail.

Respondents were also asked whether the pace of technology adoption has increased over the last five years (2017-2022). Indeed, the majority of respondents indicated that technology adoption has increased over the last five years (87.2%) in the Canadian mining sector, while a small proportion of respondents indicated that technology adoption has not increased (12.8%). Of the 12.8% of respondents who do not believe technology adoption has increased, 66.6% identify as mining company representatives, with the remainder identified as technology company and mining supply and services representatives. This may suggest that there is variation across Canada in terms of the pace of technology adoption across mine sites, which may be attributed to the size of the mining company or their capacity to successfully implement a new technology. The respondents who believe technology adoption has increased in the last five years could provide more information with a written response, which revealed several key themes. More specifically, some respondents discussed the importance of productivity and efficiency while other noted regulatory and ESG factors as well as health and safety, labour shortages, cost reductions, technology advancements, the availability of technology, and proven technologies as reasons why technology adoption has increased in the last five years.

With respect to increasing productivity and efficiency, respondents explained that mining companies desire to become more productive and achieve greater efficiency in their operations, which has increased the adoption of technologies. Of the 25 total qualitative responses with regards to the pace of technology adoption, ten respondents identified productivity, efficiency, and increased production as drivers for adoption in the last five years. One respondent identified declining labour productivity as a driver for technology adoption (Respondent 34). As discussed earlier, the mining sector is faced with declining productivity levels and scholars such as Steen et al. (2018) have suggested that mining companies must embrace innovation to achieve sustainable, long term productivity improvements.

More specifically, technology adoption has increased in the mining sector in Canada partly in response to what Respondent 8 described as a "*push to modernize and meet new production"* targets, while Respondent 23 stated, there is a "*constant need to improve mine operation efficiencies."* As suggested by Respondent 9, mining companies desire to "*become leaner and more efficient"* while Respondent 31 identified "*reduced costs, increased productivity, and profitability"* as drivers for technology adoption. For instance, Respondent 14 stated, "*our particular underground mine is getting deeper so technology can help with production efficiencies.*" Additionally, respondents discussed the greater demand placed on the industry to increase their production and overall productivity in response to existing labour shortages (Respondent 26). While Respondent 10 provided an example of production efficiencies in the face of labour shortages with the adoption of autonomous equipment:

> *Desires to increase production is also a driver for autonomous vehicles. These autonomous loaders which can have one "above ground" remote operator control multiple autonomous scoop loaders via remote control when they reach the end of a drift. Once loaded or unloaded the scoop loaders can drive back down to the ore face at the end of the drift and then the operator retakes remote control.*

Of the 25 respondents who provided more information as to why technology adoption has increased in the mining sector over the last five years, five respondents identified cost-related factors. Mining companies have adopted technologies *"to offset increased costs"* (Respondent 21) or to *"[reduce] labour costs"* (Respondent 23). While other respondents identified "*cost-benefit analysis"* (Respondent 16) and the "*willingness to experiment with improvement of the cost benefit cure"* (Respondent 19). In addition, Respondent 19 suggested that a reduction in the overall price of technology encouraged mining companies to adopt technology. Thus, according to respondents mining companies in Canada are increasingly seeking ways to reduce their labour and operating costs, which has contributed to the acceleration of technology adoption by mining companies.

Several respondents also identified the importance of a safe working environment as to why technology adoption has increased in the last five years. Of the 25 respondents who provided more information as to why technology adoption has increased in the mining sector over the last five years, seven respondents identified safer working conditions. This included the desire to improve safety for workers, increased health and/or safety concerns, and to meet stringent safety standards. For example, respondents discussed the adoption of battery electric vehicles to reduce diesel particulates in the air (Respondent 2 and Respondent 8), to reduce heat (Respondent 14), and/or to meet stringent safety regulations and requirements (Respondent 38). It is important to note that safety was often discussed alongside economic factors, which suggests that there may be underlying economic considerations also driving safety improvements through technology adoption. Some representative quotes include:

"*because technologies exist to make the work more safe and more efficient"* (Respondent 12); and "*It enhances safety and productivity"* (Respondent 29). Additionally, Respondent 10 stated: "*increased health and safety concerns. Any injury impacts production when labour is a scarce resource.*" Thus, in the context of significant labour shortages, injuries to workers can negatively impact production, which increases the importance of a safe working environment. The findings support the findings by Gruenhagen and Parker (2020) in their systematic review where safety was identified as a top driver to adopt technologies in mining discussed in the literature.

Next, ESG and regulatory compliance were also identified as key themes as to why technology adoption has accelerated in the past five years. Of the 25 respondents who provided more information as to why technology adoption has increased in the mining sector over the last five years, seven respondents identified ESG requirements and regulatory compliance. As suggested by Respondent 21, technology adoption has increased to "*address concerns raised due to ESG/GHG requirements*" while Respondent 31 identified, "*reduce carbon footprint (environmental responsibility)."* As Respondent 38 explained, "*the increase[ed] technological, health and safety, environmental and regulatory challenges associated with resource extraction have dictated that mining companies must operate at a higher level of technical proficiency in order to remain globally competitive."* This supports arguments in the existing literature that suggests ESG requirements, such as the need to reduce emissions, are drivers for technology adoption in mining (Gruenhagen and Parker, 2020).

Additional factors as to why technology adoption has accelerated discussed by participants pertained to the technology itself, more specifically related to technology maturity and availability. Respondent 24 stated, “*the availability of technology has increased as well as the maturity of said technology*.” With respect to technology maturity, technology has advanced rapidly in recent years which has enabled the sector to prove and de-risk various technologies (Gruenhagen and Parker, 2020; Ediriweera and Wiewoira, 2021). As suggested by Respondent 19, “*there [have] also been numerous published success cases on technologies like autonomous haulage and collision avoidance technologies.*” While Respondent 18 also stated: “*The maturity level of some new technologies have been proven such that they are de-risked enough for mines to adopt them. Mines have also recognized the need for new tech adoption and have made it more of an operational priority recently.”* Results also suggest that there is growing acceptance for new technology within the sector due to the growing maturity of technologies (Respondent 5). With respect to technology availability, results suggest that technology has increased in availability in the last five years which has accelerated the pace of technology adoption (Respondent 1). In addition, mining companies have gained insight from other sectors, which has further de-risked the adoption of new technology as described by Respondent 24: “*Other adjacent sectors have adopted some tech which has paved the way for risk intolerant mining companies”*.

Respondent 17 discussed in detail the emergence of forward-thinking leaders, where leaders recognize the benefits of technologies such as automation and have fostered a culture of innovation:

For many years mining was conservative in its approach to technology adoption. The mandate was to keep things simple and focus on the way things were traditionally done. This stifled the adoption of new and innovative solutions. As the traditional thinkers move on and retire this has opened the door for forward-thinking innovative leaders in the mining industry. These new leaders recognize new technology's potential in increasing efficiency and productivity and now foster a culture of innovation.

In addition, advances in communications underground have enabled the increased adoption of connected technologies. The traditional form of underground communication was leaky feeder which supported voice and data to a certain extent. Over the last 15 years, more advanced operations have begun to adopt wireless ethernet (Wifi) technology. Within the last 5 years, private LTE has seen increased adoption in mining. The backbone of communication provided by the newer technology has enabled the concept of a connected mining operation with innovations such as autonomous vehicle operation and short interval control.

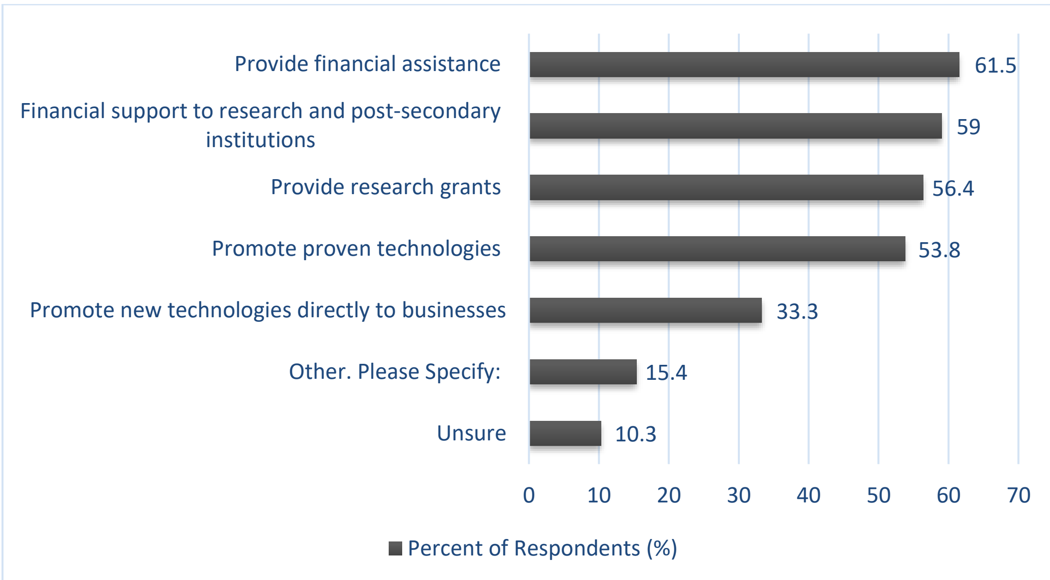
Overall, these findings suggest that the general drivers to technology adoption in the Canadian mining sector are to improve productivity and efficiency, deeper and more difficult to access mineral deposits, and health and safety standards. Productivity and efficiency improvements drive technology adoption across all industries and have been highlighted in earlier chapters. Gruenhagen and Parker (2020) also identify increased productivity/ efficiency as the top driver for technology adoption in the academic literature. In contrast with productivity and efficiency, deeper and more difficult to access mineral deposits is a mining-specific driver for technology adoption. Due to the depletion of shallow and easier to access mineral deposits, mining companies are adopting technologies that can withstand the harsh mining environment that becomes increasingly hostile and dangerous for workers at depth. At the same time, mining at depth is increasingly costly, which suggests that mining companies are ultimately adopting technologies in response to economic considerations.

Respondents also discussed the need to improve worker health and safety, such as through the adoption of electric vehicles. Results suggest that health and safety standards have accelerated the adoption of technologies in the Canadian mining sector. The next section discusses survey responses to questions on the importance of government funding and support.

4.3.1 The Role of Government

As discussed in the literature, government policy can drive or hinder technology adoption dependent upon the direction of policy. Respondents were asked about the role of government in supporting technology adoption in the mining sector. Results (Figure 3) suggest that the government supports technology adoption in a variety of ways. First, 61.5% of respondents selected that it is the role of government to provide financial assistance for technology adoption. Several studies have also noted that government investment is a driver for technology adoption, while a lack of government investment can be a barrier to adoption (Gruenhagen and Parker, 2020). Other roles selected by respondents include financial support to research and post-secondary institutions (59.0%), provide research grants (56.4%), promote proven technologies (53.8%), and to promote new technologies directly to businesses (33.3%).

Figure 3: Role of Government in Supporting Technology Adoption in the Canadian Mining Sector



*Respondents could select all choices that apply.

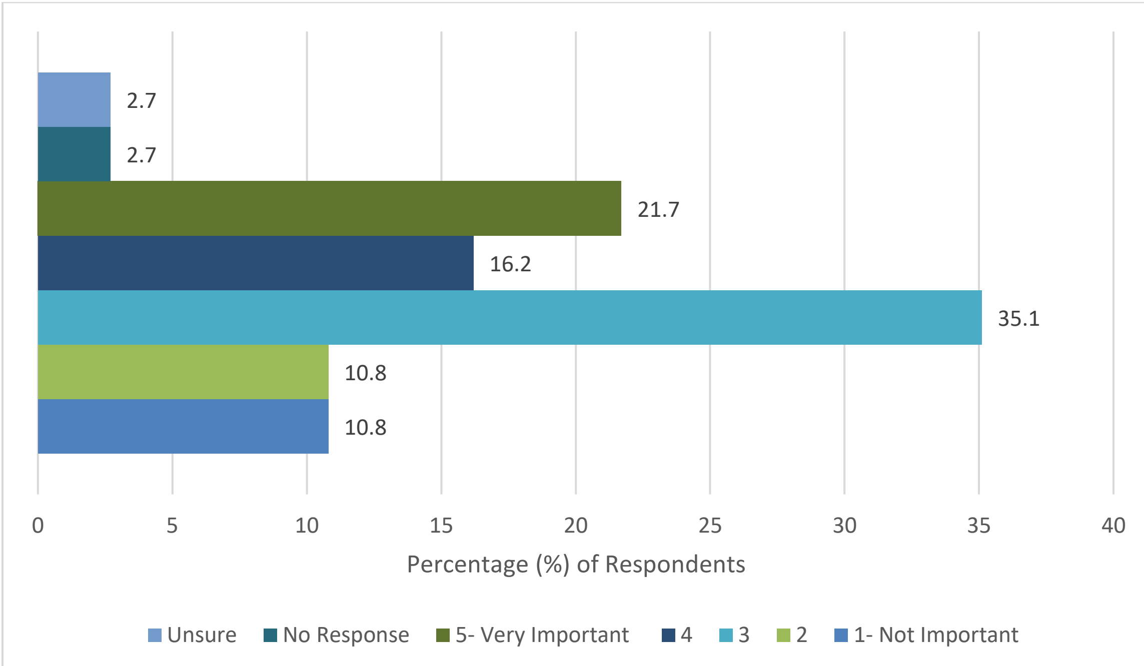
Source: Authors' Calculations.

An additional 15.4% of respondents selected 'other' and identified additional roles for government in supporting technology adoption in the Canadian mining sector. For example, Respondent 38 states that it is the role of government to "*set guidelines & regulations relative to ESG and sustainability*" while Respondent 34 stated "*laws, rules, regulatory control, standards, compliance, guidelines*." In addition, Respondent 18 stated that "*providing funds specifically for de-carbonizing technologies to mines directly would be a good move*." It is important to note that the federal government has recently introduced funding towards clean mining technology development and adoption in the extractive industries through the Strategic Innovation Fund (Government of Canada, 2023). Overall, the government does play a supportive role in the technology adoption process for mining companies by defining the regulatory framework, which can encourage technology adoption, for instance in the case of clean technologies.

Lastly, Respondent 15 identified "*reducing permit approval times."* As Söderholm et al. (2015) states, "a lack of timeliness in the regulatory decision-making process" can lead to uncertainty and concerns related to competitiveness for mining companies due to the high capital intensity of the sector (p. 135). Söderholm et al. (2015) identified ways in which the government can improve permitting delays and the timeliness of the approval process, specifically through the allocation of increased capacity, resources, and competencies to regulatory authorities; and "introducing new governance and administrative tools for improving cooperation and information exchange between the industry and the authorities" (p. 140). Therefore, the literature suggests that the government can respond to permitting delays that impede technology adoption by providing regulatory bodies with adequate resources, capabilities, and competencies required to complete the permitting process.

Next, respondents were asked about the importance of access to government funding and support in the decision to adopt a new technology, with 1 being not important and 5 being very important. As seen in Figure 4, the mean response is 3.5, which suggests most respondents felt that government funding and support is somewhat important in the decision to adopt a new technology. Mining companies acquire capital through other means, such as through institutional investors, which may explain why government funding and support was considered only somewhat important by respondents.

Figure 4: Importance of Government Funding and Support



4.4 Understanding the Technology Context

As stated in Chapters 2 and 3, this research utilizes the TOE framework with insights from the DOI theory in the technological context. The following section discusses the enablers and barriers to adoption with a focus on the technological factors. As mentioned in Chapters 2 and 3, common factors identified in the technology context include complexity of the technology, observability, compatibility of the technology with existing processes, costs, existing skills and expertise, and proven track record of the technology.

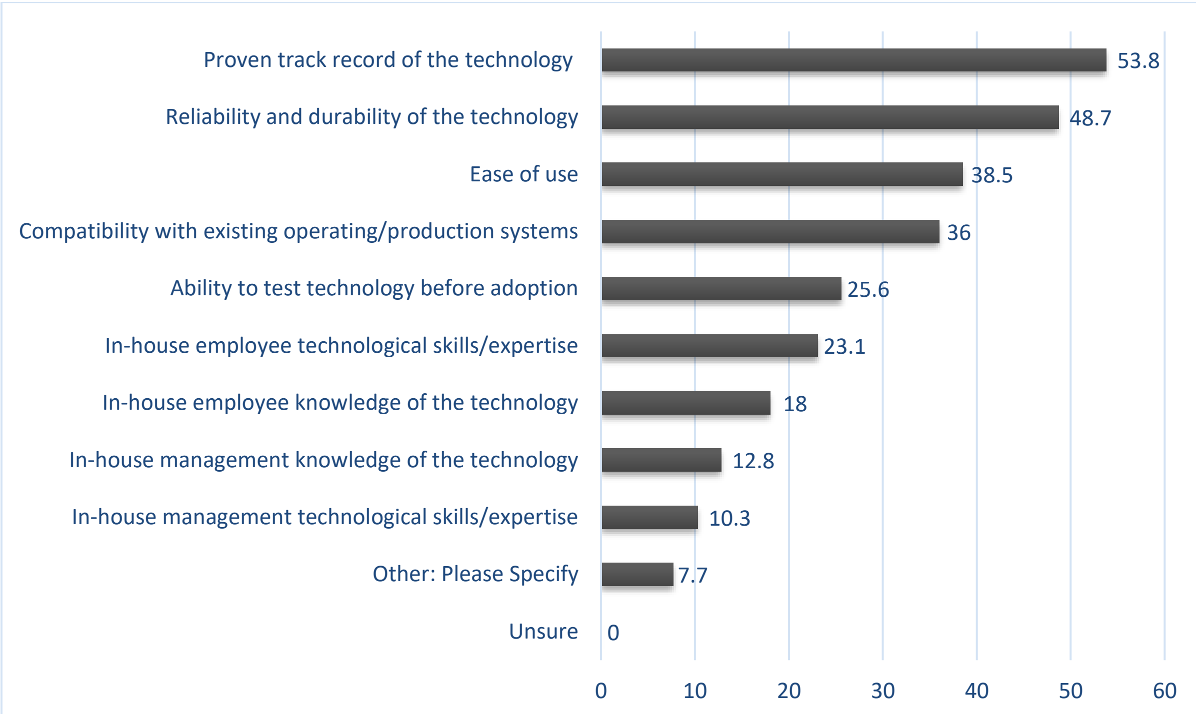
4.4.1 Technology-Related Enablers

Respondents were asked to identify up to three technology-related enablers for technology adoption (Figure 5). Overall, the proven track record of the technology in a mining environment, selected by 53.8% of respondents, was the top technology-related enabler for adoption selected by respondents. These results confirm the findings by Ediriweera and Wiewoira (2021) on Australia's mining sector that discusses the importance of technologies that have been proven to work in a mining environment prior to adoption. Additionally, in the original TOE framework developed by Tornatzky and Fleischer (1990), characteristics of specific technologies are a key factor in technology adoption decisions for organizations. In the context of the mining sector, proven track record of the technology is an important enabler for technology adoption, which also suggests that the characteristics of the technology can impact technology adoption decisions.

Respondents were provided with the opportunity to expand on their responses and some respondents provided additional information on the importance of proven technologies in a mining environment. For example, one respondent suggested that having a proven track record of a technology takes away the unknowns (Respondent 24), while another respondent stated, "*new technology is always viewed favourably if it is already proven to work*" (Respondent 21). Some respondents also suggested that mining companies adopt technologies that can integrate into existing processes without interrupting production (Respondent 33). In another example, Respondent 10 stated:

> *Proof that the solution will work reliably in the incredibly harsh mining environments is key to even considering a new Smart Mining Solution. Having tested the solution both in a Smart Mining Living Lab and where application done scalability, robustness, and applicability testing in a data or cloud environment is key to acceptability by potential customers. Ability to prove interoperability to commercial operating or production systems is also a key area to offer assurance that your product is ready for live deployment.*

Figure 5: Technology-Related Enablers



**Respondents could select up to three responses.*
Source: Authors Calculations.

Drawing on the importance of technology characteristics in the decision to adopt a technology, results from the survey also suggest that the reliability/durability of the technology in a mining environment is a top enabler for technology adoption, selected by 48.7% of respondents. Likewise, the literature suggests that in mining, technologies must be reliable and durable to withstand often harsh mining environments (Ediriweera and Wiewoira, 2021). Therefore, the results here suggest that technological characteristics are of particular importance in the decision to adopt a technology, which must be durable, reliable, and proven in a mining environment. Several respondents provided additional context, such as Respondent 24 who stated, "*reliability and especially durability is important for continued* *and uninterrupted operations."* As noted in the literature, one of the challenges for technology adoption in mining is interruptions to production, and technologies that are reliable and durable can reduce disruptions by potentially offsetting technology failures.

Survey results further suggest that the ease of use of the technology is a top enabler for technology adoption, which was selected by 38.5% of respondents. This was described by Respondent 24 who explained "*ease of operation makes it agreeable for operating personnel to use."* While Respondent 27 identified how the ease of use with which the technology can be integrated into existing processes, as well as the ease of use for operators, can enable technology adoption. As a result, training for the technology is critical to ensure ease of use for the operator:

> *The most important factor in the adoption of new technology is* ***the ease with which it can be integrated into the current mine cycle/process.*** *If a new technology adds steps to a process, it will have limited success in being adopted.* ***Training on new technology is also critical****. Companies hoping to commercialize their technology in the mining sector need to be cognizant of the training required for their technology to be implemented and used properly* (Respondent 27, emphasis added).

It is worth noting that 7.7% of respondents selected "other" as the top technology-related enabler and a variety of responses were provided. For example, one respondent stated that "*engineers tend to kill technology advancement. They tend to think more linearly and if something is off the line, they look at opportunity as risk so stay the line and avoid risk - but also avoid opportunity*" (Respondent 22). As discussed in the literature, the mining sector is risk averse due to the cyclical nature of the sector, uncertainty in health and safety hazards, and high capital intensity of mining activities. Mining companies also often take an incremental approach to innovation and technology adoption, where there is a focus on improvements to and optimization of existing technologies and processes (Doagoo et al., 2019; Steen et al., 2018). Another respondent who selected 'other' pointed to the benefit of the business case as a key enabler for technology adoption (Respondent 17) which corresponds to the technology adoption literature that suggests perceived benefits of technologies are an adoption driver (Rogers, 2003). For example, Respondent 1 stated "*decreased maintenance costs*" are a top enabler for technology adoption, which is an expected outcome of adoption.

As noted earlier, respondents were also provided with the opportunity to expand on their responses and several additional technology-related enablers for adoption were provided. The following quotes pertain to the qualitative responses provided by participants. For example, respondents discussed the importance of having a proven return on investment (ROI) and the importance of technology champions at mine sites, the age of the mine, and sustainability. With regards to the importance of a proven ROI, Respondent 24 stated:

> *Technologies that provide proven ROI and utility have the best chance of being adopted. Also, technologies that either have little training requirements or elegant and easy to learn training requirements stand a good chance. Not interrupting production is also key to adoption.*

Return on investments for technology adoption is discussed extensively in the literature, where cost is a significant barrier to technology adoption for businesses. The objective for businesses is always to reduce operating costs, and investment in new technology can be counterintuitive to reducing costs. Businesses are therefore more likely to adopt technologies that provide them with a return on their investment. The importance of a proven return on investment is also discussed in the research by Ediriweera and Wiewoira (2021), where it was also found that mining companies prioritize return on investment in their technology adoption decisions.

Respondents also discussed the importance of technology champions as a technology-related driver for adoption. Similar findings on the importance of champions at mine sites were identified by Gruenhagen and Parker (2020) in their systematic review and by Ediriweera and Wiewoira (2021) in their research on Australia's mining sector, where it was also found that technology or innovation champions are drivers for technology adoption. Results here suggest that technology champions also play an important role in the technology adoption process in the Canadian mining sector. Examples from the survey include:

> *We look for new technology at the operations and corporate level. Any new technology will have to have a 'champion' who backs its implementation. New technology is always viewed favourably if it is already proven to work. We have already adopted technology when we have a chance to trial it and can ensure that it works for our needs* (Respondent 21).

While Respondent 17 stated:

> *The forward thinkers will be aware of the problems that need to be solved and turn to technology and innovation for the solution. For example, low productivity can be improved with autonomous or automatic vehicle operation between shifts, and greenhouse gas emissions can be reduced by introducing a battery electric vehicle fleet. Any of the skills and knowledge gaps can be filled as part of the adoption plan.*

As discussed by Steen et al. (2018), mines operate as interconnected systems whereby the adoption of technology has implications for the entire system, which can be a barrier to adoption. One respondent discussed the difficulty of adopting technologies without disrupting mining operations, particularly in aging mines. Due to the high capital intensity of mining activities, any halt to production to implement technology in an existing mine can present as a deterrent to adoption due to lost production costs. However, new mine developments in Canada are being built with the infrastructure necessary to support technologies like electric vehicles which can offset lost production costs as a barrier to adoption. More specifically, Respondent 28 explained:

> *Mining companies are not early adopters as the digital transformation is difficult to complete [in] aging mines without disruptions to mine operations. Thus, new mine development [i.e.,] Borden mine and its use of battery electric vehicles and deep mines like Glencore's Onaping Deep will lead the way* (Respondent 28).

Additional responses revealed key sustainability management themes. Of note, Respondent 22 stated that technology-related enablers are technology-specific, making it difficult to select three general technology-related drivers. However, they noted that "*impact on safety, impact on the environment, addressing a social concern and impact on the bottom line*" are enablers for technology adoption in the sector. This indicates that future research on the technology-related enablers may benefit from technology-specific research through case studies on specific technologies. Likewise, in their systematic review, Gruenhagen and Parker (2020) found that improving sustainability and health and safety were among the top drivers for technology adoption in the mining sector. Respondent 12 expanded on sustainability improvements as drivers for technology adoption:

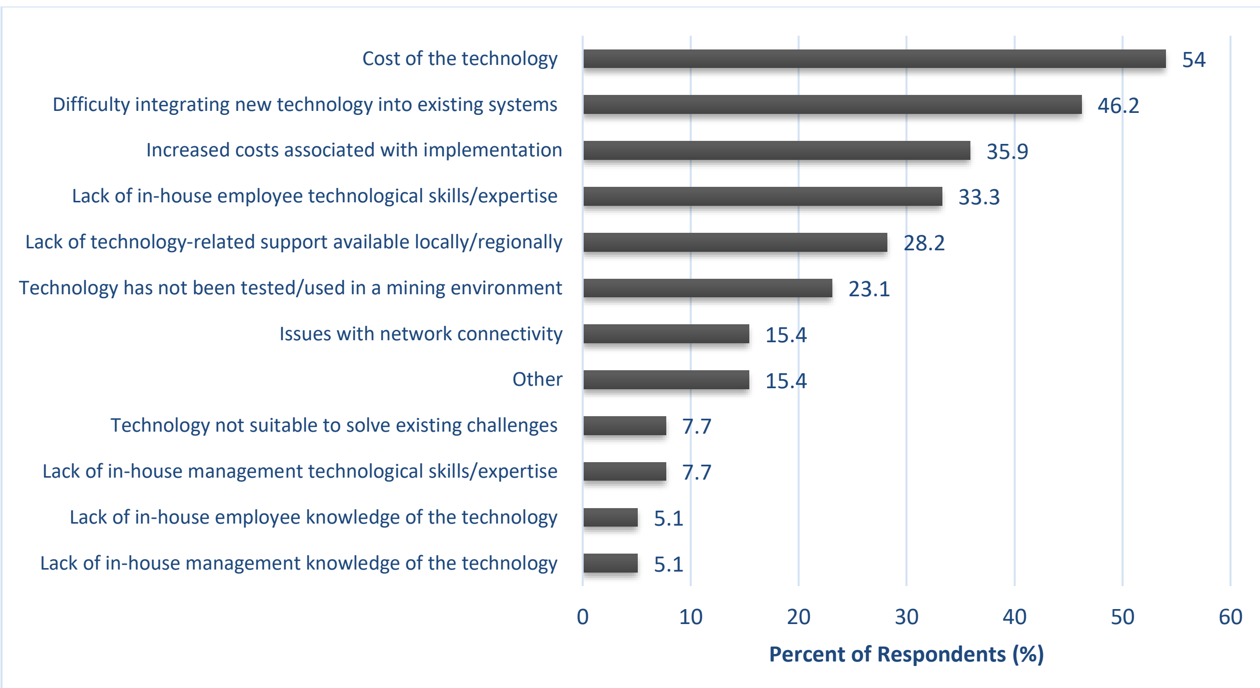
I have followed technology developments throughout my career. I believe there are ongoing improvements in safety with the monitoring of ground response to mining activities, pit slope radar monitoring, micro seismic monitoring for example. Also, technologies in mobile equipment for fatigue monitoring, and collision avoidance when using manned equipment of remote control or autonomous for unmanned equipment. Further to the safety improvement there are many examples of mining efficiency improvements with systems like dispatch or machine health monitoring to reduce maintenance costs and machine breakdown lost time. Hardware and software is becoming more advanced and robust, and all these technologies are enabling lower cost mining and safer for the miners and the environment (Respondent 12).

In summary, there are several key technology enablers identified in the survey including: a proven track record of working in a mining environment; reliability and durability in a mining environment; ease of use and the ease at which it can be integrated into a specific mining environment; the importance of health and safety; and key sustainability themes. As noted, these enablers are consistent with the literature discussed in Chapter 2. More specifically, Rogers (2003) has long argued that technologies must be easy to use for successful adoption and diffusion while in the context of mining, Gruenhagen and Parker (2020) discuss the important role of sustainability, health, and safety as enablers for technology adoption. The next section will present the results of technology-related barriers to adoption.

4.4.2 Technology-Related Barriers

Respondents were asked to identify up to three technology-related barriers for technology adoption (Figure 6). Overall, the cost of the technology, selected by 54.0% of respondents, was the top technology-related barrier for adoption in this survey. As discussed in Chapter 2, the adoption of new technology requires access to financial resources and the initial adoption of a technology can involve high upfront investment costs that create uncertainty in terms of profitability for firms (Kiel et al., 2017). As a result of high upfront investment costs, it can be difficult for firms to justify their return on investment (Horváth and Szabó, 2019). In the mining sector, Gruenhagen and Parker (2020) also found in their systematic review that investment costs/lack of financial resources is the most significant barrier to technology adoption.

Figure 6: Technology-Related Barriers



**Respondents could select up to three responses.*
Source: Authors Calculations.

Relatedly, results from this survey also suggest that implementation costs, selected by 35.9% of respondents, is a barrier to technology adoption. As discussed in Chapter 2, cost barriers are not limited to the initial purchase cost of the technology. Rather, cost barriers may also include the implementation of the technology, which may require additional costs such as the reskilling of workers and maintenance or servicing of the technology. Within the mining-specific research, Gruenhagen and Parker (2020) note that the implementation of technology can be more complex in the mining sector than in other sectors as investments tend to be associated with greater costs and risk. The results here support their findings that financial barriers can pose significant challenges for mining companies to adopt technology.

In addition, respondents were provided with the opportunity to expand on their responses, and several respondents discussed costs as a barrier to technology adoption. One respondent stated that mining companies adopt technologies to reduce overall operating costs, however being an early adopter of technology can be costly: "*an increased operating cost or complication of existing processes is counter to one of the main objectives to installing new technology. Prior implementation usually means that the technology is lower cost to implement and/or operate. - being a guinea pig can be costly*" (Respondent 21). While another respondent stated that "*mining is a business therefore impact on the bottom line or the business model associated with adoption has to make sense financially. Positive impact on revenue is desirable*" (Respondent 34). In addition, Respondent 12 explained how adoption is often hard to justify due to the costs of implementation, particularly in junior mining companies. More specifically:

> *The benefits are often hard to quantify in $$ terms and hence the cost of implementation of process improvement, safety improvement or efficiency improvement technologies is hard to justify. Many younger engineers struggle*

to persuade managers of the benefits especially in the junior mining companies (Respondent 12).

While another respondent suggested that return on investment (ROI) is an important barrier in the decision to adopt a new technology, more specifically, "*cost is a huge barrier to mining companies as there needs to be a proven return on a project, whether financial, health & safety, or environmental, in order to implement a new technology into an existing operation*" (Respondent 33). In other words, ROI can also include health and safety and environmental improvements, which highlights the growing importance of sustainability in management decisions for companies discussed in Chapter 2.

Results from this survey also suggest that the difficulty integrating a new technology into existing processes is a barrier for technology adoption, selected by 46.2% of respondents to this survey. As discussed by Steen et al. (2018), a mining operation is an interconnected system where disruptions to one area can disrupt the entire system. This is particularly relevant as mining companies adopt connectivity, LTE and/or Wi-Fi as mines become increasingly connected. One respondent provided an example of the importance of reliable network connectivity and the difficulties that can come when communication platforms fail to meet expectations:

Many of today's technologies work best when part of a connected mining operation. The importance of the communication backbone was established in a previous answer, but it is also critical to ensure the reliability of that backbone and to advance it as the mine advances.

Integration is key, and it is important that things work together. There can be a preference to adopt a mining platform that includes all the solutions sought (mine planning, surveying, personnel & vehicle tracking, collision avoidance,

> *etc.). But the platforms don't always function as promised so there is a reliance on system integrators to make everything work as desired.*
>
> *Large mining companies will have the technical staff required with the technical skills or ability to be trained to maintain newly adopted technology. Smaller companies have leaner workforces and will rely on the vendor to support the technology. These companies will rely on the vendor for support or seek an As-A-Service approach to reduce upfront capital while the vendor operates the system on site (for example battery-charging-As-A-Service).* (Respondent 17).

Of the total responses to this survey, 15.4% of respondents selected 'other' as a barrier to technology adoption, with responses ranging from a lack of understanding of the industry among technology providers (Respondent 26) to long lead times for technologies (Respondent 3) as barriers to adoption. An additional respondent discussed resistance from government to adjust regulations to account for new technologies as a barrier to technology adoption:

> *Difficulties and resistance from governments to adjust the regulation to consider the benefit of the new technologies. As an example, the ventilation required for underground equipment is still based on HP [horsepower] and is not considering the fact that battery vehicles are not producing emissions. New technology is much more expensive and we're not having the benefit of the improvement* (Respondent 13).

As discussed in Chapter 2 and earlier in this Chapter, government regulations can either drive, enable, or slow technology adoption depending on the rate and direction of policy. More specifically, Respondent 13 provided an example of government regulations acting as a barrier to adoption in the case of BEVs. The respondent explained that existing regulations for ventilation have not been updated to account for new technologies such as BEVs, which produce zero emissions and significantly less heat than diesel vehicles. They further argued that ventilation requirements are typically based on the power of the equipment fleet, therefore companies are required to invest in the same ventilation regardless of the vehicle type (diesel or electric) or its' emissions. It may be important to note that Respondent 13 is a large (>500 employees) mining company representative with operations in British Columbia. Ventilation requirements in the mining sector are within provincial jurisdiction, and the example provided by Respondent 13 is specific to British Columbia. Additionally, government regulations can also be understood as an environmental barrier to technology adoption, as government regulation and policy is one of the factors captured in the environmental context for this research.

Other responses in the "other" category included a lack of access to external maintenance support for the technology as a barrier for adoption. For example, one respondent explained: "*maintenance provided by an external source needs to be accessible within a tight time frame. If that is not possible the technology cannot be considered due to the risk of that technology failing. Support is extremely important*" (Respondent 23). External services and maintenance support can also be classified as an environmental factor in the adoption process, as it is dependent on the commercial services provided by external companies.

The results on technology-related barriers point to key themes related to costs and the difficulty of integrating technology into existing operating systems. Likewise, in their systematic review Gruenhagen and Parker (2020) identify investment costs/lack of financial resources as the most discussed barrier to adoption in the literature. Additionally, one respondent in this survey indicated that cost is a more significant barrier for smaller companies while larger companies have access to the training and support required to implement new technology. This may point to the importance of firm size in the context of mining for technology adoption decisions. Lastly, sustainability was also identified in the responses, where return on investment includes not only financial returns but also improvements to health, safety, and environmental sustainability.

4.5 Understanding the Organizational Context

Next, respondents were asked to identify the organization-related factors that act as enablers or barriers to technology adoption. As mentioned in Chapters 2 and 3, under the TOE framework organization-related factors that can act as enablers and barriers to adoption include access to slack resources, communication processes, formal and informal linkages within the company, corporate culture, KPI (Knowledge Performance Indicators) structure, and the willingness of employees to adopt a new technology.

4.5.1 Organization-Related Enablers

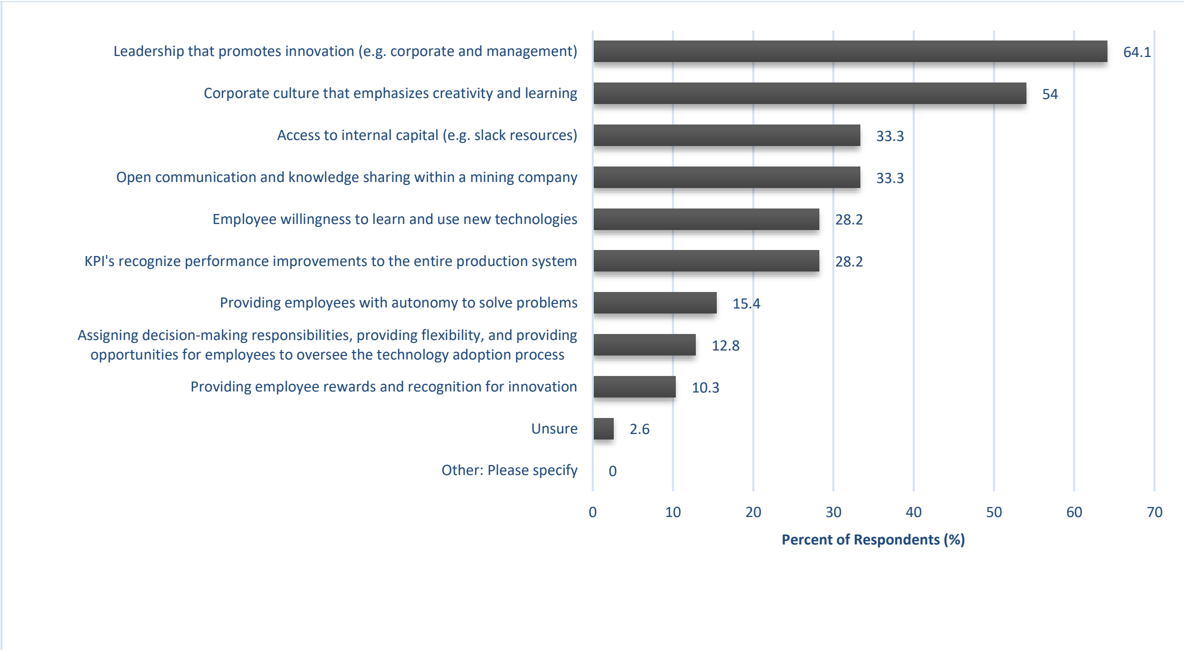
Respondents were asked to identify up to three organization-related enablers for technology adoption (Figure 7). The top organization-related enabler for technology adoption was leadership that promotes innovation (e.g., corporate and management), selected by 64.1% of respondents. Respondent 17 further discussed the importance of leadership that promotes innovation:

> *Companies that have seen the most success in the adoption of technology have forward-thinking leaders who foster a culture of innovation and technology adoption. That has to be driven from the top down. Pushing from the bottom*

> *or middle up is rarely successful and has to be motivated by more than just the passion for technology.*
>
> *I've seen this firsthand at Kemi Mine in Finland more than 15 years ago where employees were encouraged to develop innovative ideas and were pulled from their roles temporarily to realize the implementation of their ideas* (Respondent 17).

As mentioned in Chapter 2, the literature suggests that leadership that promotes innovation at the corporate and management level can enable technology adoption for all industries (Baker, 2012; Ediriweera and Wiewoira, 2021). Gruenhagen and Parker (2020) also identified how leadership that promotes a culture of innovation is a driver for technology adoption. In contrast, organizations with leadership that emphasizes efficient, reliable operations instead of innovation can discourage employees from their creativity and risk taking even in cases when given autonomy, out of fear of consequences for their actions (Jung et al., 2003). As such, a culture of innovation is considered an enabler for technology adoption at the organizational level.

Figure 7: Organization-Related Enablers



**Respondents could select up to three responses.*

Source: Authors Calculations.

Another top organization-related enabler for technology adoption, selected by 54.0% of respondents, is a corporate culture that emphasizes creativity and learning (e.g., opportunities for experimentation, occasional failures and testing of new technologies). Respondents were provided with the opportunity to expand on their responses and several respondents discussed the importance of a company culture that supports innovation in the adoption of new technology. For example, Respondent 21 stated that the "*company has to encourage innovation and creativity.*" Respondents also indicated that central to a culture of innovation is "*enabling and trusting frontline management to make decisions*" (Respondent 24). A couple of respondents further stated that more risk taking is an enabler for technology adoption. While Respondent 10 stated "*A culture of innovation within the mining company is going to go a long way to accommodating new innovative solutions for sure. However, a way of introducing new technologies in small experimental zones to reduce risk would also be useful.*" Building on this response, experimental zones can allow mining companies to test technologies in their specific mining environment without the risk of negative impacts to production. As mentioned in Chapter 2, the ability to test a technology before adoption through demonstration projects, can drive technology adoption in the mining industry (Gruenhagen and Parker, 2020).

Furthermore, Chapter 2 also discussed the importance of having a culture of innovation which was cited as a driver for technology adoption by Gruenhagen and Parker (2021). Similarly, Ediriweera and Wiewoira (2021) state that a culture that emphasizes creativity and learning can enable technology adoption for mining companies. Their research highlights that a culture with opportunity to experiment, occasional failures and testing of new technologies prior to adoption is paramount for successful technology adoption to overcome the structural barriers embedded in the mining sector, such as high capital intensity and the cyclical nature of the boom-and-bust cycles.

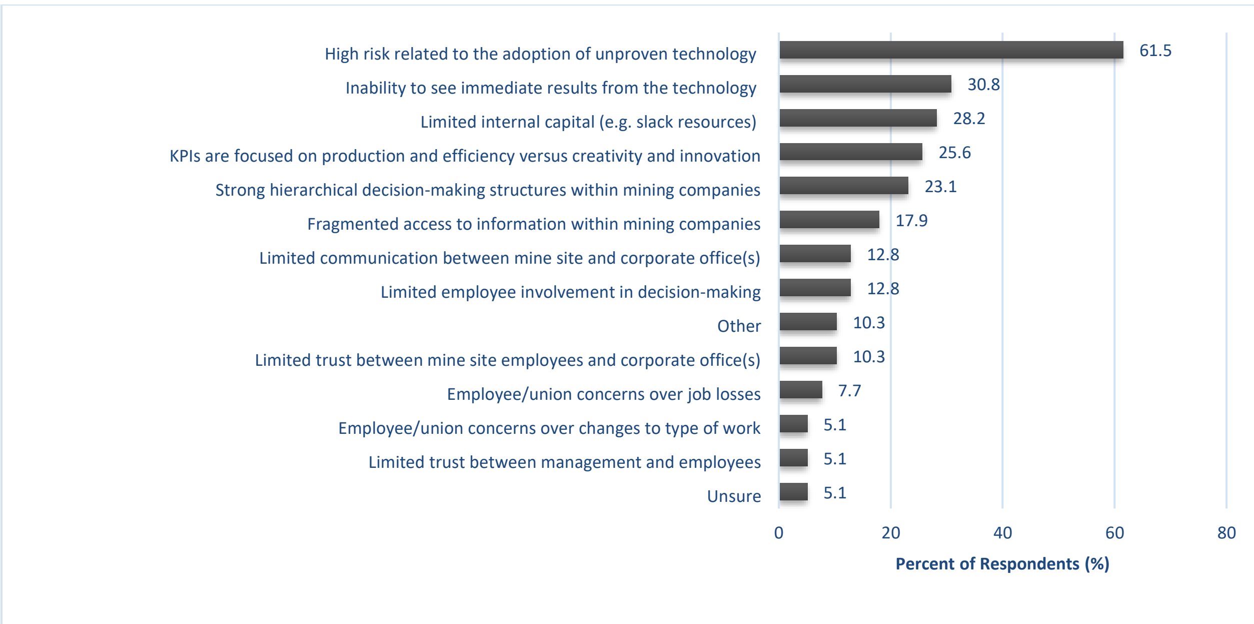
The third top organization-related enabler for technology adoption according to the survey results was access to internal capital (e.g., slack resources), selected by 33.3% of respondents. Slack resources for all industries can enable firms to absorb risk, purchase and implement a new technology (Nystrom et al., 2002). In the context of the mining sector, Gruenhagen and Parker (2020) explain how a lack of financial capital required to adopt a new technology is a significant barrier to adoption. Results of this survey are similar in that access to financial capital is an enabler for adoption. With the high capital intensity of the mining sector, access to internal capital can enable mining companies to absorb the potentially high investment and implementation costs of technologies and thus enable adoption. No respondents selected ‘other’ for organization-related enablers.

The results on organization-related enablers for technology adoption have strong linkages to the literature on organizational culture. The work by Ediriweera and Wiewoira (2021) is particularly relevant where they argue that leadership that promotes innovation and a corporate culture that emphasizes creativity and learning can enable technology adoption for firms. Respondents in this research also cited forward-thinking leaders and an organizational culture that supports innovation and creativity as paramount for successful adoption.

4.5.2 Organization-Related Barriers

Respondents were then asked to identify up to three organization-related barriers to adoption (Figure 8). The top organization-related barrier was the high risk related to the adoption of unproven technology, selected by 61.5% of respondents. As discussed in Chapter 2, the adoption of new, unproven technology in mining often involves significant risk, due to potential safety hazards, the risk of technology failure and increased production costs. As a result, there is a focus on risk avoidance towards technologies which can lead to hesitancy among workers and create a barrier to adoption. As established earlier, the costs of investment tends to be high in the mining sector, which can also contribute to a risk averse mindset. Intangible factors such as risk aversion, however, can be more challenging to overcome than tangible factors such as access to internal capital (Gruenhagen and Parker, 2020).

Figure 8: Organization-Related Barriers



**Respondents could select up to three responses.*
Source: Authors Calculations.

The next organization-related barrier for technology adoption was the inability to see immediate results from the technology selected by 30.8% of respondents. As discussed in Chapter 2, in the context of Australia, the inability to see immediate results from technology adoption can also contribute to risk aversion towards new technologies. Mining companies tend to prioritize short-term production targets to satisfy shareholders, and the benefits from technology adoption are often only realized over the long-term, which can have negative impacts on short-term production targets and discourage investment and adoption of a specific technology (Ediriweera and Wiewoira, 2021). Results to this survey suggest that mining companies in the Canadian mining sector also prioritize short term benefits from a technology, while the inability to see immediate results from a technology is a barrier to adoption.

The third most prevalent organization-related barrier was limited internal capital (e.g., slack resources), selected by 28.2% of respondents. This was further explained by Respondent 13 who stated, "*the cost of new technology is really expensive and without [a] grant, it's mainly impossible to justify the investment*." As discussed extensively in Chapter 2, the costs of a technology, its maintenance, and its implementation are barriers to technology adoption. More specifically, the mining sector is capital intensive and with the high costs of technology, it is difficult to justify new technology investment (Gruenhagen and Parker, 2020). These findings support the academic literature, specifically that of Gruenhagen and Parker (2020) who also identify a lack of financial resources as the top barrier to technology adoption in the mining sector.

It is worth noting that key performance indicators (KPIs) that are focused on production and efficiency versus creativity and innovation was also selected as a barrier by 25.6% of respondents. Both Steen et al. (2018) and Ediriweera and Wiewoira (2021) suggest that existing KPI structures can be barriers to technology adoption in the mining sector, as there is an emphasis on short term production targets and individual productivity, where employees are not rewarded for involvement in the technology adoption process. Technology adoption can negatively impact KPIs in cases where production is disrupted, and employee performance indicators are adversely impacted. Steen et al. (2018) also suggests that KPI structures that consider the entire mining system is more conducive to innovation than existing KPI structures that focus on individual daily production targets.

Finally, 10.3% of respondents selected ‘other’ for top organizational barriers and listed a variety of barriers, all of which also link to the technology context in the TOE framework. For example, Respondent 11 stated, “*adoption of technology into current processes*” is a barrier for technology adoption. As discussed in Chapter 2 and earlier in Chapter 4, compatibility of the technology with existing mining operations is identified as a technology-related driver for adoption, while the difficulty of integrating a new technology into an existing mine is identified as a barrier to adoption. Compatibility of technology was first identified by Rogers (2003) in the DOI theory and continues to be a commonly cited factor in the technology context in recent studies that utilize the TOE framework (i.e. Bhattacharyya and Shah, 2022). In addition, Gruenhagen and Parker suggest that technology adoption in the mining sector is more complex than in other industries due to high capital intensity and high risk. While Steen et al. (2018) states that it can be difficult to implement a new technology into a mine because mines are interconnected systems, and the adoption of a new technology can have implications for the entire mine. As such, adoption of technology into current mining processes is a barrier identified by the findings and supports the existing literature. While Respondent 22 emphasized, "*Limited employee and management experience outside a very very narrow expertise*".

In comparison to the technology context, less respondents elaborated on their responses, however some provided additional insights. For example, one respondent discussed how technology adoption might impact employment as a barrier to adoption. The respondent suggests that while heavy equipment operators may decrease, the losses will be offset by a greater need for mechanics and equipment service/maintenance personnel:

> *Many of the innovations going into mining improve employee safety and ensure miners are engaged in more meaningful and interesting higher value work. However, no question some autonomous equipment does mean fewer below ground equipment operator jobs may be required. More mechanics and equipment service/maintenance personnel may be required instead of equipment operators* (Respondent 10).

Another respondent discussed the gap between knowledge at the mine site and at the corporate office: "*there is a gap between corporate strategy and execution on site. That gap should be bridged with a site technology leader or champion that is responsible for the adoption of technology but accountable to the site to ensure alignment with operational needs*" (Respondent 17). Again, the findings suggest that an on-site technology champion is important in the Canadian mining sector. One explanation as suggested by Respondent 17 may be the gap between corporate strategy and operations at the mine site.

Overall, the key themes identified for the organization-related barriers include the high risk related to the adoption of unproven technology, the inability to see immediate results from the technology, and limited internal capital. As mentioned, the mining sector is often seen as risk averse towards technology adoption due to the risks to production and safety of workers, particularly in the case of unproven technologies. Additionally, the inability to see immediate results from a technology can act as a barrier to technology adoption in the Canadian mining sector, as companies tend to prioritize short-term production targets. Often, benefits of a technology are not apparent until the technology has been fully integrated into a mine, and the implementation of a new technology can lead to unexpected challenges that entail an uncertain degree of risk, which can deter technology adoption. I turn now to a discussion of the environmental context.

4.6 Understanding the Environment Context

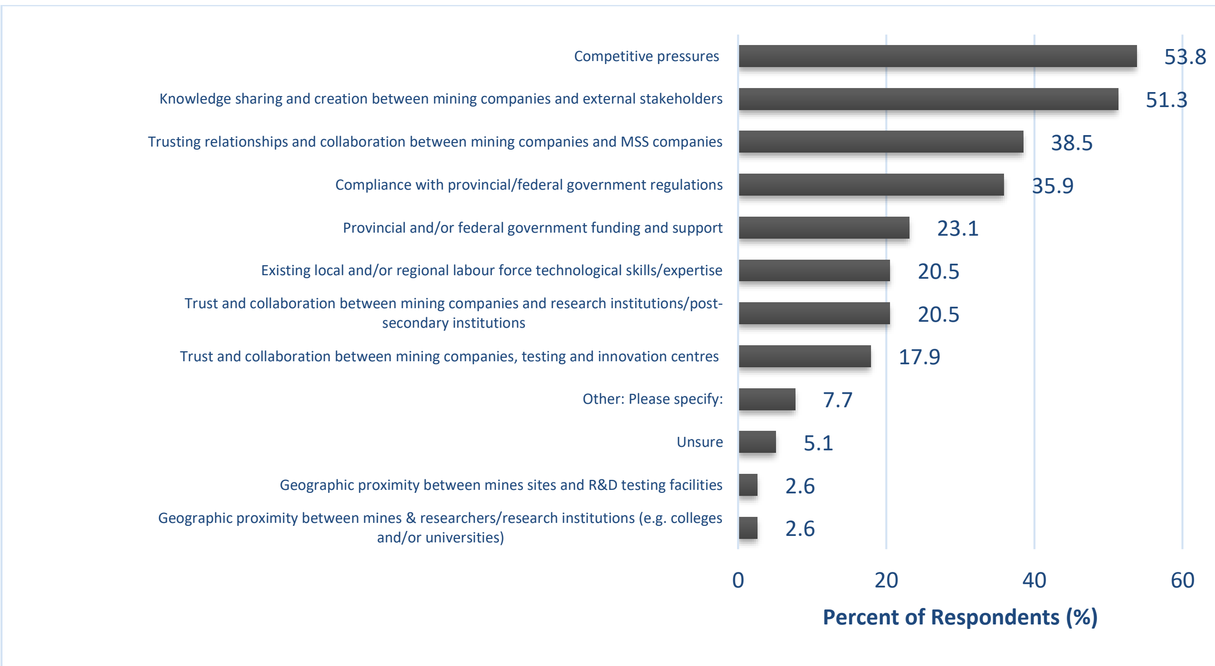
After assessing factors in the technology and organizational contexts, respondents were asked to identify the enablers and barriers for technology adoption in the environmental context. As discussed in Chapters 2 and 3, this often includes competitive pressures, collaboration and knowledge sharing with external stakeholders, government support and regulations, existing labour force skills and expertise, and geographic proximity between mine sites and head offices.

4.6.1 Environmental-Related Enablers

Respondents were asked to identify up to three environmental-related enablers to technology adoption (Figure 9). Overall, respondents selected competitive pressures as the top enabler for technology adoption in the Canadian mining sector, which was selected by 53.8% of respondents. As discussed in Chapter 2, the mining sector has responded to competitive pressures in the market with the adoption of technological innovations, such as automation

(Gruenhagen and Parker, 2020). For example, in Australia, Rio Tinto has developed a strategy to increase mine automation to maintain its competitive position in the global mineral and metals market and respond to a wide variety of economic and social competitive pressures that have resulted from globalization (The International Institute for Sustainable Development; 2018).

Figure 9: Environment-Related Enablers



**Respondents could select up to three responses.*
Source: Authors Calculations.

The next top selection by respondents was knowledge sharing and creation between mining companies and external stakeholders (e.g., research institutions, post-secondary institutions, innovation centres, mining supply and services companies etc.), which was selected by 51.3% of respondents. As discussed in Chapter 2, knowledge sharing with external stakeholders can reduce risks, build trust, and establish co-creation partnerships, which enables cooperation and allows external stakeholders to better understand a specific mine's characteristics and requirements (Ediriweera and Wiewiora, 2021). Turning to trust, 38.5% of respondents selected trusting relationships and collaboration between mining companies and with mining supply and services companies as a top enabler in the environmental context for technology adoption. As highlighted by Ediriweera and Wiewoira (2021) in Chapter 2, trust between mining companies and external stakeholders can increase communication and knowledge sharing for the sector. Additionally, collaboration with external stakeholders can enable the development of functional networks, which can increase the speed and rate of technology adoption (Ediriweera and Wiewiora, 2021; Caiazza and Volpe, 2017). For example, as described by Warrian (2020) some companies, such as Hatch, have established long-term partnerships with their clients, which enables the customization of a specific technology to the needs of a specific client. The literature suggests that the Canadian mining sector is increasingly prioritizing a collaborative approach towards technology adoption, rather than the traditional transactional relationship between mining companies and suppliers (Doagoo et al., 2022).

Additionally, while not among the top three enablers, compliance with provincial or federal government regulations was selected as a top enabler by 35.9% of respondents. While provincial and/or federal government funding and support was selected by 23.1% of respondents. These findings suggest that the government can play a key role in enabling technology adoption in the mining sector. Similarly, Gruenhagen and Parker (2020) note that government regulations are a driver for technology adoption. As discussed earlier in the results and in the environmental context of the TOE framework in Chapter 2, the nature of government regulations and policy can influence the technology adoption process for all industries, as regulators identify the legal constraints of the industry. Interestingly, in this research geographic proximity between mines sites and R&D testing facilities, and geographic proximity between mines and researchers/research institutions (e.g., colleges and/or universities) were both only selected as a driver by 2.6% of respondents.

Again, respondents were able to select "other" which revealed important sustainability themes. One respondent indicated that approval from local Indigenous communities is an enabler for adoption (Respondent 3) while another respondent stated that pressures to reduce GHG emissions drives technology adoption (Respondent 13). More specifically, Respondent 22 identified "*reducing environmental impact, demand for raw materials, reduced OPEX [operating expenditures] and CAPEX [capital expenditures]*" as environmental enablers for technology adoption. In their systematic review, Gruenhagen and Parker (2020) identified sustainability as the third most-discussed driver for technology adoption in the literature. The results here are, therefore, consistent with the existing literature that sustainability is an important enabler for technology adoption in the mining sector in Canada. No additional qualitative responses were expanded on for environmental enablers.

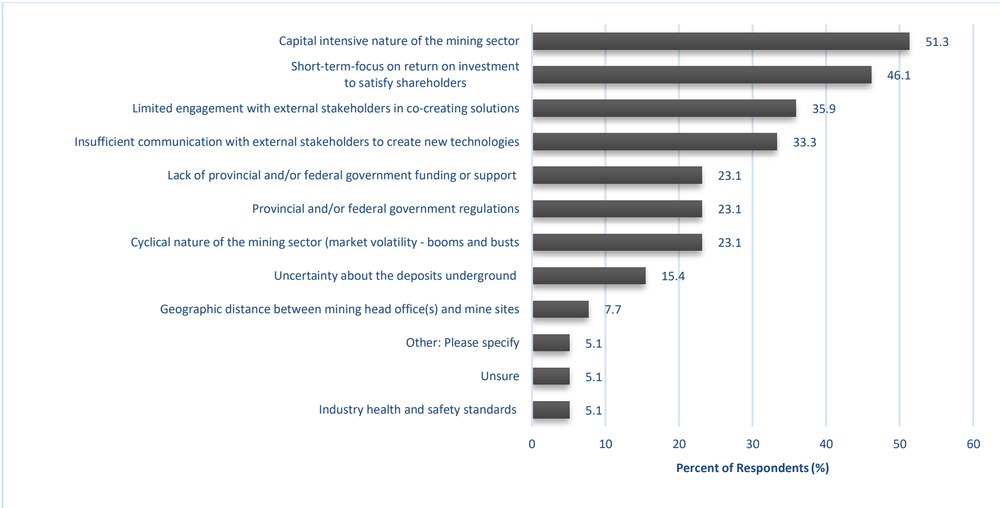
In summary, the key themes identified as environmental enablers for technology adoption include competitive pressures in the global mineral and metals markets, technology support and infrastructure (i.e., collaboration, trust, communication, and knowledge sharing with external stakeholders), government regulations and support, and sustainability. As discussed in previous chapters, the mining sector is a highly competitive industry that is faced with increased pressures to meet upcoming mineral and metals demands, reduce emissions, minimize the social impacts of mining activities, and maintain competitiveness on a global scale. Additionally, results here support some of the arguments put forth by Ediriweera and Wiewoira (2021) with regards to the importance of knowledge sharing and creation, as well as trusting and collaborative relationships with external stakeholders for successful technology adoption in the mining sector. While few respondents elaborated on their choices with a qualitative response, the literature suggests that knowledge sharing, creation, collaboration and trusting relationships are imperative for the formation of functional networks, which can increase the speed of technology adoption for all industries (Caiazza and Volpe, 2017). Additionally, while not amongst the top three environmental enablers, it is important to note that compliance with government regulations was cited as a driver for technology adoption, which suggests that the government does have a role to play in enabling technology adoption in the mining sector. Lastly, responses emphasize the importance of sustainability, where reduced environmental impact, GHG emissions and gaining approval from Indigenous peoples are enablers for technology adoption in mining in Canada.

4.6.2 Environmental Related Barriers

Respondents were asked to select up to three environmental-related barriers to technology adoption (

Figure **10**). The top barrier, selected by 51.3% of respondents, was the high capital intensity of the mining sector. This is consistent with the literature, which argues that the mining sector is capital intensive and that this results in structural barriers to innovation such as a conservative culture and firm inertia (Bartos, 2007; Gruenhagen and Parker, 2020). Capital intensity can also result in lock-in effects, where technologies and processes become entrenched, which can impact technology investment and adoption decisions as the implementation of technologies can cause disruption to existing operations. More specifically, as discussed in Chapter 2, Ediriweera and Wiewoira (2021) identified high capital intensity as a barrier to technology adoption in the Australian mining sector because it can limit investments in technologies.

Figure 10: Environment-Related Barriers



**Respondents could select up to three responses.*

Source: Authors Calculations.

Related to the high capital intensity of the mining sector, a short-term-focus on return on investment to satisfy shareholders was the second most selected environmental barrier to technology adoption, selected by 46.1% of respondents. Similar findings were identified by Ediriweera and Wiewoira (2021) in their research on Australia's mining sector, where they also found that a short-term focus on ROI to satisfy shareholders is an environmental barrier to technology adoption. More specifically, while it is of particular importance to satisfy shareholders in mining because it is a highly capital driven industry, the adoption of technology can negatively impact short-term production targets and shareholder value. As discussed in Chapter 2, technology adoption is not a linear process, and benefits from adoption are often realized over a longer term. As a result, technology adoption might not be conducive to meeting short term production targets. Which means, mining companies will prioritize productivity to maximize shareholder dividends (Ediriweera and Wiewoira, 2021).

The third environmental barrier for technology adoption selected was the limited engagement with external stakeholders in co-creating solutions (e.g., research organizations, mining supply and services companies etc.), selected by 35.9% of respondents. When provided with the opportunity to expand on their responses, Respondent 18 suggested, more collaborative and applied R&D would help to address barriers to technology adoption Similarly, the research on Australia's mining sector suggests that engagement with external stakeholders is limited. Ediriweera and Wiewoira (2021) found that mining companies are hesitant to trust the skills and capabilities of research organizations which can limit the ability to build trusting relationships and collaborate on co-creating technologies. Their research revealed that often, mining companies partner with research organizations due to pre-existing relationships or low costs rather than for their capabilities or knowledge. In the case of mining supply and services companies, the lack of engagement with mining companies in co-creating solutions means that suppliers are not provided with all of the information required to develop the technology to function within a specific mining system, which can then create challenges during implementation of the technology.

While not among the top three drivers, industry characteristics were identified by some respondents as barriers to technology adoption. For example, the cyclical nature of the mining sector (market volatility – booms and busts) was selected as a top barrier by 23.1% of respondents, uncertainty in the deposits underground was selected as a top barrier by 15.4% of respondents, and geographic distance between mining head office(s) and mine sites was selected by 7.7% of respondents. Interestingly, the research by Gruenhagen and Parker

(2020) suggests that the geographically remote nature of mining creates challenges for technology adoption, while Ediriweera and Wiewoira (2021) identified the geographic dispersion between mine sites and head offices as a top environmental barrier for technology adoption in the context of Australia. However, respondents in this survey did not select geographic distance as a top barrier to adoption in the context of the Canadian mining sector.

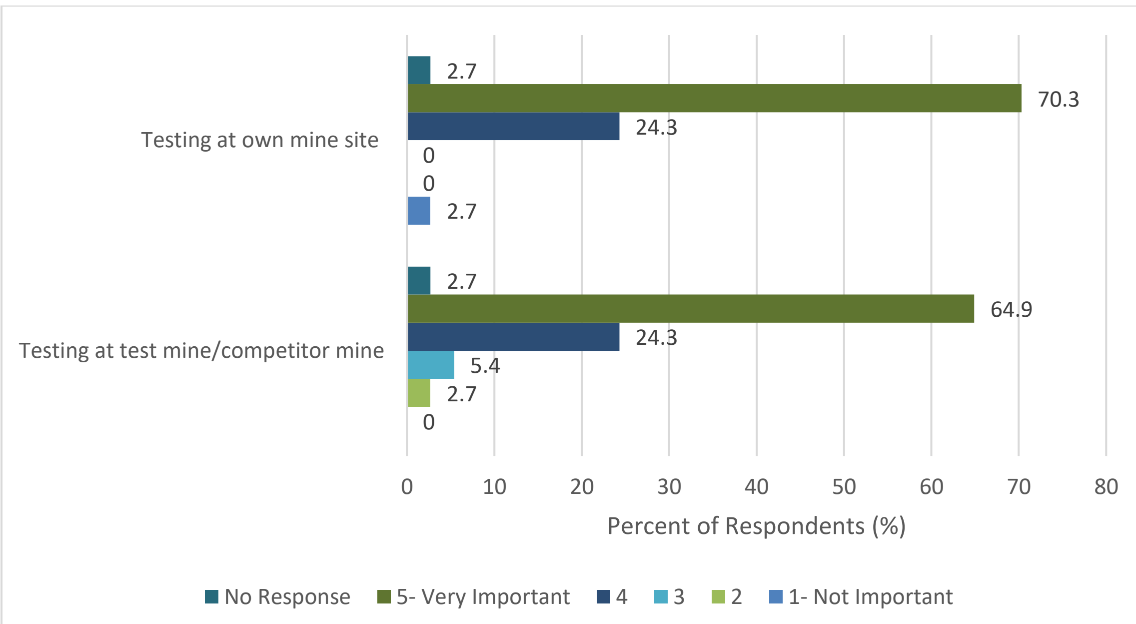
It is worth noting that 5.1% of respondents selected "other" for environmental barriers to technology adoption and the responses varied. For example, Respondent 22 pointed to the bad reputation of the mining sector in comparison to other industries with direct environmental implications as an environmental barrier to technology adoption: "*The bad reputation the mining industry has. Real estate development has no stigma but destroy the environment forever, mining rehabilitated after extraction/ processing is complete. And the environmental review on mining is intense. It's not for real estate development, forestry, farming or infrastructure projects."* In addition, when provided with the opportunity to expand on their responses, Respondent 24 discussed the siloed nature of mining professionals as a barrier to technology adoption: "*It is constantly surprising how siloed mining professionals can be. Technology solutions exist in a number of adjacent sectors but are not deemed suitable or are not known about due to the lack of a reference customer in mining*".

In summary, key themes identified for the environmental barriers include the capital-intensive nature of the sector, short-term focus on return on investment to satisfy shareholders, and limited engagement with external stakeholders in co-creating solutions. As mentioned, the mining sector is capital intensive due to the high cost associated with mine development and maintenance. As a result, it can be difficult for mining companies to justify investments in new technology. At the same time, this high capital intensity can result in lock-in effects where technologies become entrenched and existing processes or technologies are preferred. Related to this, is the short-term focus on return on investment (ROI) to satisfy shareholders. Mining companies are reliant on their shareholders to fund their operations, and the adoption of a new technology could negatively impact shareholder value, which can deter mining companies from investing in and adopting new technology. Lastly, limited engagement with external stakeholders is identified as a barrier to technology adoption. As discussed earlier, the mining sector is often reliant on technology providers for innovations, who should be familiar with a mine's specific conditions and needs. However, limited engagement with external stakeholders can limit the supplier's ability to develop the necessary solutions to fit the client's needs, which can be a barrier to technology adoption.

4.7 Additional Factors that Influence Adoption

The concluding questions asked respondents to rate the importance of several additional factors that influence technology adoption identified through the literature. First, respondents were asked how important it is for a company to test new technology at their mine in the decision to adopt a new technology, with 1 being not important and 5 being very important. As seen in Figure 11, the mean was 4.3. This suggests that most respondents felt that it is very important to test a technology at a specific mine site in the decision to adopt a new technology. Next, respondents were asked how important is knowing that the technology has been tested or been used previously underground (e.g., a test mine facility or competitor mine) in the decision to adopt a new technology, with 1 being not important and 5 being very important. The mean response was 4.2, which again suggests that most respondents felt that knowing a technology has been tested either at a test mine or a competitor mine is important in the decision to adopt a technology (Figure 11).

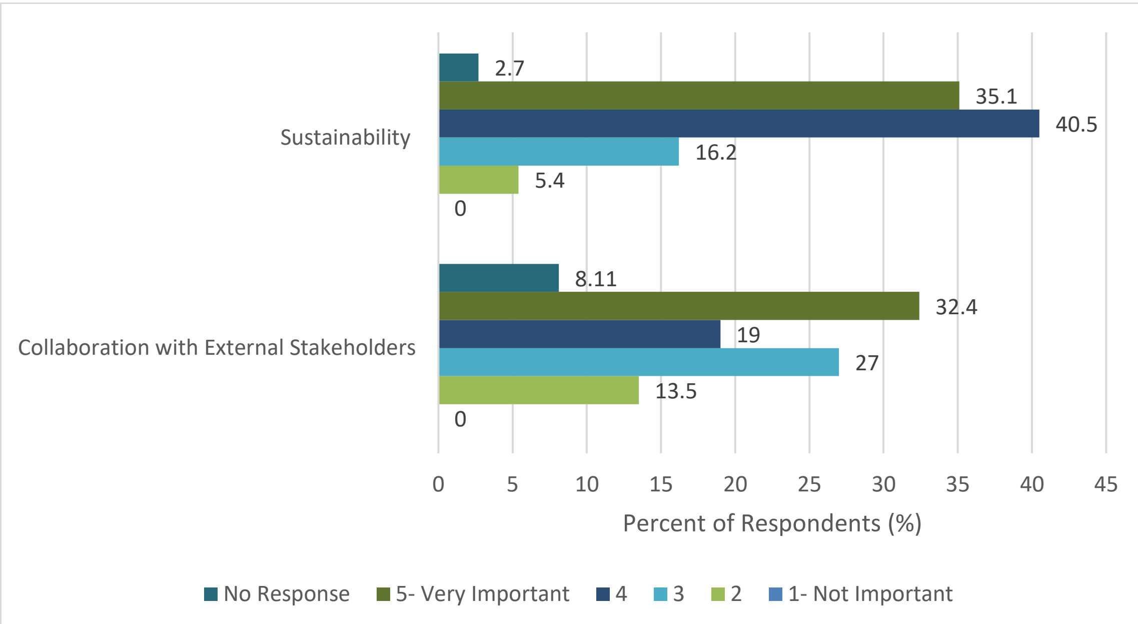
Figure 11: Importance of Testing Technology Prior to Adoption



Source: Authors' Calculations.

Then, respondents were asked to rate the importance of sustainability in the decision to adopt technology. The mean response was 4.1 and as shown in Figure 12, the results suggest that sustainability is considered an important driver in the decision to adopt technologies in the Canadian context. Respondents were then asked about the importance of collaboration with external stakeholders in the decision to adopt technology. The mean response was 3.8, and as shown in Figure 12, the results suggest that most respondents perceive collaboration with external stakeholders as important to technology adoption in the mining sector.

Figure 12: Importance of Sustainability and Industry Collaboration



Authors' calculations.

4.8 Chapter Conclusions

These results have contributed to a better understanding of the factors that influence technology adoption in the Canadian mining sector. Technologies adopted by mining companies in the last five years in Canada include battery electric vehicles (BEVs), sensors, and autonomous equipment. Canadian mining companies have also adopted technologies such as 5G or LTE, drones, and mapping for geospatial data and visualization. With respect to technology procurement, results indicate that mining companies in Canada are primarily consumers of innovation and rely heavily on technology suppliers for new technologies. The reliance on technology providers for technology solutions has also been discussed by other researchers (Steen et al., 2018). With respect to where mining companies acquire their technologies, results indicate that most mining companies in Canada acquire their technologies internationally or nationally.

The findings also demonstrate that, according to respondents, technology adoption has accelerated in the last five years (2017-2022) in the Canadian mining sector. The mining sector is faced with challenges due to a decline in labour productivity; the depletion of shallow, easy-to-access mineral deposits; increased operating costs; environmental and regulatory challenges; and growing health and safety concerns; wherein technologies such as battery electric vehicles and autonomous operations have enabled mining companies to respond to such challenges and continue to maintain their global competitiveness. Thus, while economic considerations are of concern as with all businesses, mining companies are motivated to adopt technologies for a multitude of factors that includes improvement in the health and safety for workers, and to address the social and environmental impacts of mining operations.

4.8.1 Technology Adoption Enablers

This research also identified enablers to technology adoption in the Canadian mining sector based on the TOE Framework (Tornatzky and Fleischer, 1990). With respect to the technology context, the enablers identified by respondents demonstrate that the characteristics of the technologies themselves can enable technology adoption. Results of this survey indicated that technology characteristics of importance to the mining sector include that the technology is proven, reliable, durable, and easy to use. For technology providers, an understanding of the training requirements needed to successfully adopt and implement their technology in a mining environment is necessary to successfully commercialize their technology.

In the organizational context, the overarching enablers for technology adoption are top management support, a culture of innovation and access to slack resources. With respect to a culture of innovation, results indicated that leadership that promotes innovation at the corporate and management level is an enabler for technology adoption in the Canadian mining sector. More specifically, respondents stated that forward-thinking leaders who foster a culture of innovation can enable the adoption of technologies. Thus, results suggest that leadership plays an instrumental role in technology adoption in the mining sector. Additionally, a corporate culture that encourages creativity and learning through the opportunity to experiment with occasional failure, to test new technologies and take risks is an enabler for adoption identified in this research. More specifically, respondents identified trust in front-line management to make decisions with respect to the introduction of new technologies or ideas as an enabler for technology adoption in the mining sector. These results strongly support the findings by Ediriweera and Wiewoira (2021) on the importance of a culture of innovation within the mining sector for successful technology adoption. Furthermore, with respect to the role of slack resources in the decision to adopt a new technology, results suggested that access to internal capital enables technology adoption in the Canadian mining sector. Due to the high capital intensity of the mining sector and their financial commitments to shareholders, access to financial capital enables companies to absorb high investment and implementation costs to allow for the adoption of technologies.

Additionally, the testing of technologies in small experimental zones was identified as an enabler for adoption in this research, which was also discussed in the context of Australia’s mining sector (Ediriweera and Wiewiora, 2021). As stated by Ediriweera and Wiewoira (2021), technology adoption in small experimental zones can enable mining companies to minimize risk, uncertainty, and reduce impacts to daily production targets. Experimental zones can also promote a culture of innovation as operators can gain familiarity with a new technology in an environment that allows for the occasional failure and testing of the technology.

In the environmental context, key enablers for technology adoption selected by respondents include competitive pressures in the global mineral and metals markets, technology support and infrastructure (i.e., collaboration, trust, communication, and knowledge sharing with external stakeholders), government regulations and support, and sustainability. Competitive pressures as enablers for technology adoption in the mining sector may suggest that mining companies in Canada are adopting technologies in response to adoption among their competitors, which can help to de-risk the technology and thus encourage adoption.

As mentioned, enablers for technology adoption as cited by respondents also include knowledge sharing and collaboration with external stakeholders such as research institutions, post-secondary institutions, innovation centres, mining supply and services companies. The results from the survey suggest that the Canadian mining sector does recognize collaboration for successful technology adoption and implementation as an enabler for technology adoption. This supports existing findings in the literature that suggest that while the Canadian mining sector was hesitant to collaborate in 2016, the mining sector is increasingly prioritizing a more collaborative approach towards technology adoption, rather than the traditional transactional relationship between mining companies and suppliers (Doagoo et al., 2022). Trust and collaboration between mining companies and with mining supply and services (MSS) companies is also identified as an enabler for technology adoption in the Canadian mining sector. As highlighted by Ediriweera and Wiewoira (2021) in Chapter 2, trust between mining companies and external stakeholders can increase communication and knowledge sharing for the sector. Again, results strongly support the findings by Ediriweera and Wiewoira (2021) on the importance of trust and collaboration within the mining ecosystem for technology adoption.

While not among the top three enablers, additional enablers in the external environment selected by respondents include compliance with provincial and federal government regulations, which supports existing findings in the literature on technology adoption and the mining sector. As discussed in Chapter 2, the nature of government regulations and policies establishes the legal constraints of an industry, which can influence technology adoption for all industries (Tornatzky and Fleischer, 1990). In the context of the mining sector, Gruenhagen and Parker (2020) found that government regulations can drive technology adoption in the mining sector. The results here demonstrate that government policies and regulations can also enable technology adoption in the Canadian mining sector. Lastly, as mentioned, sustainability appeared as an enabler for technology adoption throughout the survey. Respondents suggested that approval from local Indigenous communities, pressures to reduce GHG emissions and overall environmental impacts, as well as an increased demand for raw materials are key enablers for technology adoption in the external environment.

4.8.2 Technology Adoption Barriers

In the technology context, barriers include the costs of technology, increased costs associated with implementation of the technology, and incompatibility between the technology and existing operating systems. With respect to costs, respondents explained that positive impacts on revenue are of critical importance to mining companies, therefore it is often difficult to justify the high costs of technology investments. It was also suggested that junior mining companies can have greater difficulties than large mining companies in the adoption of new technologies due to barriers related to cost. With respect to incompatibility between the new technology and existing operating systems, some respondents explained that technologies must integrate effectively into a connected mining system once adopted, which can be challenging in the mining sector where each mine is made up of unique technologies, ore bodies and organizational structures. Therefore, compatibility (Rogers, 2003) is a determinant in the adoption of technologies for mining companies in Canada.

In the organizational context, barriers include high risk related to the adoption of unproven technology, a short-term focus on return on investments, and limited internal capital. Again, economic considerations, specifically the lack of slack resources, was identified as a barrier to adoption in the organizational context. As mentioned, the mining sector is highly risk averse, and the adoption of unproven technologies can increase risks and uncertainty that inevitably arise in the technology adoption process. Furthermore, results also highlight organizational challenges, such as a lack of cohesion between the execution of strategy at corporate offices and mine sites, as a barrier to adoption.

In the environmental context, the top three barriers to technology adoption identified by respondents are the capital-intensive nature of the mining sector, a short-term focus on return on investments, and limited engagement with external stakeholders in co-creating solutions. The findings are consistent with the environmental barriers to adoption in Australia's mining sector (Ediriweera and Wiewoira, 2021). Additionally, industry characteristics such as the high capital intensity of the sector and a short-term focus on ROI are consistent with the findings by Tornatzky and Fleischer (1990) that industry characteristics can influence the technology adoption process. Additional industry characteristics that impede the adoption process identified in the results include the cyclical nature of the mining sector and uncertainty in the mineral deposits underground. Lastly, in contrast with the existing literature on Australia's mining sector, geographic proximity between the mine site and corporate head offices, test centres or research institutions did not appear as a barrier to technology adoption in Canada's mining sector, which may be a testament to Canada's strong mineral supply and services (MSS) sector among other factors.

Chapter 5: Conclusion

5.1 Introduction

The objective of this thesis was to identify the drivers, enablers, and barriers to technology adoption in the Canadian mining sector with an online survey distributed to representatives in the Canadian mining sector. Based on a review of the technology adoption literature, the Technology-Organization-Environment (TOE) Framework was utilized to frame this research, which sought to answer the following research questions:

(1) What technologies are being adopted in the mining sector in Canada?

(2) What is driving the adoption of these technologies?

(3) What factors are barriers to the adoption of new technologies?

(4) What factors are enablers to the adoption of new technologies?

The findings suggest that there are many factors identified as drivers, enablers and barriers to technology adoption for mining companies with operations in Canada. The top three drivers for technology adoption are to increase productivity/efficiency, to reach deeper and more difficult-to-access minerals, and to improve the health and safety of workers. Additional drivers of note but not among the top three drivers include labour shortages, ESG/CSR targets, and environmental concerns. Table 14 lists the top three enablers and barriers to technology adoption identified in the technology, organization, environment contexts. Overall, the main theme revealed in this research is the interplay between economic, social and environmental pillars of sustainability. As noted throughout Chapter 4, when adopting a new technology, mining companies often prioritize economic factors such as improvements in productivity and a positive return on investment (ROI). However, social factors such as worker health and safety also ranked highly while respondents also reflected on how new technologies could help address environmental impacts.

Table 14: Enablers and Barriers for Technology Adoption in the Mining Sector in Canada

	Technology	Organization	Environment
Enablers	Proven track record of the technology	Leadership that promotes innovation (i.e., corporate and management)	Competitive pressures
	Reliability/durability of the technology	Corporate culture that emphasizes creativity and learning	Knowledge sharing and creation between mining companies and external stakeholders
	Ease of use of the technology	Access to internal capital	Trusting relationships and collaboration between mining companies and MSS companies
Barriers	Cost of the technology	High risk related to the adoption of unproven technology	Capital intensive nature of the mining sector
	Difficulty integrating new technology into existing operating systems	Inability to see immediate results from the technology	Short-term focus on return on investment
	Increased costs associated with implementation	Limited internal capital	Limited engagement with external stakeholders in co-creating solutions

Authors' Own.

5.2 Key Insights

As demonstrated throughout this research, technology adoption is accelerating in the Canadian mining sector in response to various pressures facing the industry, such as deeper and more difficult-to-access mineral deposits, greater demand for raw materials, rising operating costs, the need to maintain a social license to operate, to improve worker health and safety, and to reduce the environmental impacts that inevitably arise from mining activities. Indeed, the mining sector has reached an "inflection point" wherein technologies have been deemed necessary to sustain a competitive advantage within the changing market dynamics of the global mining sector (Lay et al., 2022, p. 2).

The top technologies adopted by Canadian mining companies identified in this survey over the last five years include battery electric vehicles, sensors, and autonomous equipment. The top three drivers to adopt technologies are increases in productivity and efficiency; to reach deeper and more difficult-to-access mineral deposits; and to improve the hea lth and safety of workers. Several respondents provided examples of the benefits that can be acquired through the adoption battery electric vehicles, which demonstrated that BEVs can allow mining companies to improve the three dimensions of sustainability, namely economic sustainability through a reduction in ventilation costs, environmental sustainability through the elimination of GHG emissions, and social sustainability through improvements to worker health and safety in the elimination of diesel particulates in the air.

The use of the TOE framework reveals that technology adoption in mining entails a complex interplay of factors across the commonly cited pillars of sustainability (economic, social, environmental). The top enablers and barriers for technology adoption identified in the survey demonstrate that mining companies prioritize economic factors in the technology adoption process. More specifically, in the technology context, a positive return on investment (ROI) is discussed by respondents as an enabler for adoption, while costs of the technology and its associated implementation costs are barriers for adoption. In the organizational context, access to internal capital enables adoption, while a lack of internal capital is seen as a barrier for adoption. Finally, in the environmental context, competitive pressures enable adoption, while the high capital intensity and short-term focus on return on investments are barriers for adoption. Therefore, economic factors play an influential role across technology, organization and environmental contexts. These economic factors are mediated by social factors such as the health and safety of workers, and environmental factors, such as the reduction of overall GHG emissions. Respondents demonstrated that for mining companies in Canada, the return on investment for technology adoption includes not only financial returns, but also improvements to health and safety, environmental sustainability, and social impacts of mining activities.

The findings also identified key differences from the research on Australia's mining sector by Ediriweera and Wiewoira (2021). More specifically, Ediriweera and Wiewoira (2021) identified that geographic proximity between mine sites and corporate head offices is a barrier to technology adoption in Australia's mining sector. As discussed throughout this research, mining operations are often located in regions that are both geographically remote and isolated (Hall, 2017), which can create impediments to the exchange of information, access to resources and coordination between work sites (Ediriweera and Wiewoira, 2021). However, this research did not find that geographic proximity to corporate head offices is a barrier to technology adoption in Canada's mining sector. Some respondents did, however, note that greater trust in frontline management to make technolog adoption decisions could help to enable adoption. This suggests that more research is needed into the relationship between innovation and the role of proximity in the Canadian mining sector. As suggested by Boschma (2005), it is important that geographic proximity is not examined “in isolation” as there are additional forms of proximity, specifically cognitive, organizational, social, and institutional, that can also help to strengthen coordination efforts with respect to innovation within organizations. Greater trust in frontline management to make technology-related decisions may suggest that other forms of proximity, such as some degree of social proximity, could enable technology adoption in the Canadian mining sector.

Finally, a review of the existing literature on the TOE framework in Chapter 2 and responses to the survey reveal key insights for using the TOE framework to inform technology adoption research. First, this research supports the findings by Oliveira and Martins (2011) with respect to the importance of combining frameworks to increase the validity of the TOE framework. Important variables that drive technology adoption for firms, such as productivity and efficiency, are not well captured by the TOE framework. However, economic factors are captured by Rogers’ (2003) DOI theory, where he identifies relative advantage among the five innovation characteristics that impact technology adoption. Economic factors of relevance in this research, such as increased productivity and efficiency, can be captured by researchers as relative advantage or perceived benefits in future studies that combine the DOI and TOE frameworks.

5.2 Suggestions for Future Research

As noted throughout this research, literature on technology adoption in the mining sector is limited, even more so within the context of Canada. Therefore, this research was exploratory in nature and sought to provide insight into the technology trends, drivers, enablers, and barriers to technology adoption in the context of the Canadian mining sector. Several key areas for future research were identified. First, more research is needed to better understand the geographical context as to where mining companies in Canada acquire their technologies. While results to the survey suggest that mining companies in Canada acquire their technologies from national or international suppliers to a greater extent than provincial or local suppliers, more insight is needed to determine the exact factors that have led to a greater reliance on national or international technology and equipment suppliers than suppliers of closer geographic proximity (possible explanations include international ownership of OEMs, or established relationships built with multinational OEMs). To acquire greater economic benefits from mining activities domestically, it may be worthwhile to investigate ways in which mining companies in Canada can strengthen their relationships with local suppliers.

Furthermore, the results suggest that future research on technology adoption in the Canadian mining sector may benefit from case studies specific to one technology. More specifically, a case study exploring the drivers, enablers, and barriers to the adoption of battery electric vehicles, sensors or autonomous technologies may reveal adoption determinants specific to the technologies themselves that otherwise cannot be captured without technology-specific research. As noted by one of the respondents, it is difficult to identify the technology-specific enablers or barriers to adoption because the factors vary across different technologies.

It may also be worth further examining the role of organizational culture as an enabler for technology adoption in the mining sector. This research suggests that a culture of innovation is an enabler for technology adoption for mining companies operating in Canada, which supports similar findings in Australia's mining sector on the importance of an organizational culture of innovation (Gruenhagen and Parker, 2020; Ediriweera and Wiewoira, 2021). However, the mining sector has long been understood to have a conservative culture that is highly risk averse and resistant to change, with structural barriers that impede technology adoption, such as high capital intensity (Bartos 2007). The existing literature on organizational culture states that cultural barriers that can slow or impede the rate of technology adoption in mature industries include risk aversion, top-down decision making and rigid, siloed, bureaucratic structures (Bartos 2007; Kashan et al., 2022), each of which have been used to characterize the mining sector (Steen et al., 2018; Gruenhagen and Parker, 2020).

As noted by Kashan et al. (2022), more insight is needed into which specific cultural values promote innovation in the mining sector. Their research sought to better understand organizational culture in the Australian mining sector and identify ways in which mining companies can support a culture of innovation. Through interviews with mining industry experts in Australia, they found that risk aversion and the high capital intensity of the sector are barriers to the willingness to innovate, while creativity and risk tolerance were identified as cultural values necessary to support a culture of innovation in the Australian mining sector. Similar research in the context of the Canadian mining sector may help to identify ways in which mining companies can support a culture of innovation and thus help to enable technology adoption. The acceleration of technology adoption in the Canadian mining sector in recent years may prove to help to foster a culture of innovation, as technological innovations "provide mining firms with learning opportunities to develop the knowledge and capabilities they need to deal with emerging threats and opportunities" (Kashan et al., 2022, p. 4). Therefore, it remains to be seen whether mining companies are shifting from a conservative culture that is resistant to change, to fully embrace a culture of innovation.

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Appendix A

<u>Survey Questions:</u>

Section 1 - General Questions

1. Please state your role within Canada’s mining industry:

a) Mining company representative
b) Mining supply and services company representative
c) Non-profit mining industry organization representative
d) Municipal, provincial, or federal government representative
e) Technology company representative
f) Other. Please specify: ___________

**if a, b, or e: How many employees does your company employ in Canada?

a) 1-99
b) 100-499
c) >500
d) Unsure

2. Which province or territory is your company or organization located in? (NWT and Nunavut have been excluded from this project due to research licensing and project time constraints) (please select all that apply).

a) British Columbia
b) Alberta
c) Saskatchewan
d) Manitoba
e) Ontario
f) Quebec
g) Newfoundland and Labrador
h) Prince Edward Island
i) Nova Scotia
j) New Brunswick
k) Yukon

3. In your opinion, what are the top three technologies that have been adopted by Canadian-based mining companies over the last 5 years?

a) Autonomous Equipment
b) Autonomous Operations
c) Battery electric vehicles
d) RFID wearable sensors
e) Sensors on equipment (e.g., to detect hazards, improve safety, etc.)
f) Connectivity, 5G, LTE
g) Mapping (e.g., geospatial data and visualization)
h) Drones
i) New Ventilation
j) Artificial Intelligence (e.g., use of data and analytics to improve decision making and safety)
k) Other. Please specify: __________

4. In your opinion, how are most new technologies acquired by Canadian-based mining companies?

a) Developed in-house
b) Purchased externally
c) Co-developed in-house with external partner(s) (e.g mining supply and services company, researcher, researcher institute)
d) Unsure
e) Other. Please specify: ________

5. In your opinion, where are most new technologies acquired by Canadian-based mining companies?

a) Locally (within 100km of the mine-site)
b) Provincially
c) Nationally
d) Internationally
e) Unsure

6. In your opinion, what is driving technology adoption in the Canadian mining sector over the last five years? (Please select your top three reasons)

a) Deeper and more difficult to access mineral deposits
b) Environmental concerns
c) Corporate Social Responsibility (CSR) and/or Environmental Social Governance (ESG)
d) Health and safety hazards
e) Depleting access to resources needed for mining operations (e.g., energy)
f) Labour shortages
g) Increase productivity and efficiency
h) Compliance with government regulations
i) Unsure
j) Other. Please specify: ____________

7. In your opinion, has the rate of technology adoption by mining companies increased over the past 5 years in Canada?

Yes/No/Unsure

***If yes, why has technology adoption increased in the last 5 years? As a reminder, anonymous quotations may be used and identified by your general role and geographic location in the mining industry (e.g. Ontario mining company respondent).

8. In your opinion, what is the role of government in supporting the adoption of technology in the Canadian mining sector? (Click all that apply)

a) Provide financial assistance
b) Provide research grants
c) Promote proven technologies
d) Promote new technologies directly to businesses
e) Financial support to research and post-secondary institutions
f) Unsure
g) Other. Please specify: ___________

Section 2 – Questions about the technology factors that influence the decision to adopt new technologies by Canadian-based mining companies

9. In your opinion, what are the top three technology enablers for adopting a new technology?

a) Ease of use
b) In-house employee technological skills/expertise
c) In-house employee knowledge of the technology
d) In-house management technological skills/expertise
e) In-house management knowledge of the technology
f) Reliability and durability of the technology in a mining environment
g) Ability to test the technology at an existing mine site owned by the company before adoption
h) Proven track record of the technology underground/in a mining environment (e.g., at another mine site or test mine)
i) Compatibility with existing operating/production systems
j) Unsure
k) Other. Please specify: _________

10. Would you like to provide more information on why you selected these reasons? As a reminder, anonymous quotations may be used and identified by your general role and geographic location in the mining industry (e.g. Ontario mining company respondent).

11. In your opinion, what are the top three technology barriers for adopting a new technology?

a) Cost of the technology
b) Increased costs associated with implementation
c) Issues with network connectivity
d) Difficulty integrating new technology into existing operating/production systems
e) Technology is not suitable to solve existing challenges
f) Lack of in-house employee technological skills/expertise

g) Lack of in-house employee knowledge of the technology
h) Lack of in-house management technological skills/expertise
i) Lack of in-house management knowledge of the technology
j) Technology has not been tested/used underground or in a mining environment
k) Lack of external technology-related service and maintenance support available locally/regionally (e.g. from mining supply and services companies)
l) Unsure
m) Other. Please specify: ________

12. Would you like to provide more information on why you selected these reasons? As a reminder, anonymous quotations may be used and identified by your general role and geographic location in the mining industry (e.g Ontario mining company respondent).

Section 3 – Questions about the organizational factors that influence the decision to adopt new technologies by Canadian-based mining companies

13. In your opinion, what were the top three organizational enablers to adopting a new technology?

a) Access to internal capital (e.g., slack resources)
b) Corporate culture that emphasizes creativity and learning (e.g., opportunities for experimentation, occasional failures and testing of new technologies)
c) Open communication and knowledge sharing within a mining company
d) Key performance indicators which recognize performance improvements to the entire production system, not simply the performance of a single work unit
e) Providing employee rewards and recognition for innovation
f) Providing employees with greater autonomy to adopt solutions to solve problems
g) Assigning decision-making responsibilities, providing flexibility, and providing opportunities for employees to oversee the technology adoption process
h) Leadership that promotes innovation (e.g., corporate and management)
i) Employee willingness to learn and use new technologies
j) Unsure
k) Other. Please specify ________

14. Would you like to provide more information on why you selected these reasons? As a reminder, anonymous quotations may be used and identified by your general role and geographic location in the mining industry (e.g. Ontario mining company respondent).

15. In your opinion, what are the top three organizational barriers to adopting a new technology?

a) High risk related to the adoption of unproven technology
b) Inability to see immediate results from technologies
c) Limited trust between management and employees
d) Limited trust between mine site employees and corporate office(s)
e) Limited communication between mine site employees and corporate office(s)
f) Low emphasis on employee creativity and learning
g) Key performance indicators (KPIs) are focused on production and efficiency versus creativity and innovation
h) Limited employee involvement in decision-making
i) Strong hierarchical decision-making structures within mining companies
j) Fragmented access to information within mining companies
k) Employee/union(s) concerns over job losses
l) Employee/union concerns over changes to the type of work
m) Limited internal capital (e.g., slack resources)
n) Unsure
o) Other. Please specify: ________

16. Would you like to provide more information on why you selected these reasons? As a reminder, anonymous quotations may be used and identified by your general role and geographic location in the mining industry (e.g Ontario mining company respondent).

Section 4 – Questions about the environmental factors that influence the decision to adopt new technologies

17. In your opinion, what were the top three environmental enablers for adopting a new technology?

a) Competitive pressures
b) Provincial and/or federal government funding and support
c) Compliance with provincial or federal government regulations
d) Geographic proximity between mines sites and R&D testing facilities
e) Trusting relationships and collaboration between mining companies and research institutions/post-secondary institutions
f) Geographic proximity between mines and researchers/research institutions (e.g., colleges and/or universities)
g) Trusting relationships and collaboration between mining companies and test mines and innovation centres (e.g., incubators, commercialization centres)
h) Trusting relationships and collaboration between mining companies and with mining supply and services companies
i) Knowledge sharing and creation between mining companies and external stakeholders (e.g., research institutions, post-secondary institutions, innovation centres, mining supply and services companies etc.)
j) Existing local and/or regional labour force technological skills/expertise
k) Unsure
l) Other. Please specify: ____________

18. Would you like to provide more information on why you selected these reasons? As a reminder, anonymous quotations may be used and identified by your general role and geographic location in the mining industry (e.g., Ontario mining company respondent).

19. In your opinion, what are the top three environmental barriers for adopting a new technology?

a) Limited engagement with external stakeholders in co-creating solutions (e.g., research organization, mining supply and services companies etc.)
b) Insufficient communication with external stakeholders to create new technology solutions
c) Uncertainty about the deposits underground
d) Cyclical nature of the mining sector (market volatility – booms and busts)
e) Geographic distance between mining head office(s) and mine sites
f) Capital intensive nature of the mining sector

g) Short-term-focus on return on investment to satisfy shareholders
h) Industry health and safety standards
i) Provincial and/or federal government regulations
j) Lack of provincial and/or federal government funding or support
k) Unsure
l) Other. Please specify: ____________

20. Would you like to provide more information on why you selected these reasons? As a reminder, anonymous quotations may be used and identified by your general role and geographic location in the mining industry (e.g. Ontario mining company respondent).

Section 5: Concluding Questions

Please state the level of importance of the following technology-related factors regarding the adoption of new technologies in the mining industry in Canada (Where 1 = Not Important and 5 = Very Important)

21. How important is it for a company to test a new technology at their mine in the decision to adopt a new technology?

1 2 3 4 5 Do not know No response

22. How important is knowing the technology has been tested or used underground (e.g. a test mine facility or competitor mine) in the decision to adopt a new technology?

1 2 3 4 5 Do not know No response

23. How important is access to government funding and support in the decision to adopt a new technology?

1 2 3 4 5 Do not know No response

24. How important is collaboration with external stakeholders (i.e. research organizations, post-secondary institutions, and/or government) in the decision to adopt a new technology?

1 2 3 4 5 Do not know No response

25. How important is increasing sustainability in the decision to adopt a new technology?

1 2 3 4 5 Do not know No response

Appendix B

Information and Consent Letter

Research Study Title: Exploring Technology Adoption in the Mineral Mining Industry in Canada

Student Investigator: Mackenzie Crabbe (School of Environment, Enterprise and Development, University of Waterloo)

Faculty Supervisor: Dr. Heather Hall (School of Environment, Enterprise and Development, University of Waterloo)

You are invited to participate in a survey for a master's research study entitled "Exploring Technology Adoption in the Mineral Mining Industry in Canada." The purpose of this research is to explore the drivers, enablers, and barriers of technology adoption in the mining industry in Canada. This research study is also part of a larger, national research study entitled Remote Controlled: Technology in the Mining Sector and the Future of Development in Rural and Northern Regions led by Dr. Heather Hall at the University of Waterloo. Summaries of the data from this survey may be shared with the national research team to inform the broader project.

Research Study Information: The mining sector has traditionally been viewed as slow to adopt new technologies, and there is a gap in the literature on the factors that drive technology adoption in the mining industry, particularly in Canada. To address this gap, this research will explore the drivers, enablers, and barriers to technology adoption in the mining sector in the Canadian context (excluding Nunavut and NWT). More specifically, it seeks to answer the following research questions: (1) what technologies are being adopted in the mining sector in Canada; (2) what is driving the adoption of these technologies? (3) what factors are barriers to the adoption of new technologies? and (4) what factors are enablers to the adoption of new technologies? Technologies might include autonomous equipment, autonomous operations, battery electric vehicles, RFID wearables, sensors on equipment, 5G technologies, LTE networks, mapping technologies, drones, new ventilation, and artificial intelligence. This research is specific to the Canadian mineral mining industry and excludes oil and gas mining.

Your Participation: You are being asked to complete a 15-minute online survey. Given your role as [e.g., Mining industry representative, mining company representative], we feel that you would be well suited to participate in this research. Survey questions focus on topics such as what emerging technologies are being adopted in the Canadian mining sector, and what factors enable the decision to adopt technologies. Your participation in this study is voluntary. You may decline to answer any questions that you do not wish to answer, and you can withdraw your participation during the survey by not submitting your responses. After submitting your responses, however, consent cannot be rescinded as survey submissions remain anonymous and there is no way for us to verify which responses are yours.

Potential Benefits: The potential benefits by participating in this study include providing the mining industry with knowledge on what factors enable technology adoption in the mining industry, as well as what factors act as barriers in the decision to adopt emerging technologies. Furthermore, this research will help fill a gap in the literature on the adoption of technologies in the mining sector in Canada. Additionally, this research will provide insights into the industry for policymakers on the innovation support needed for technology adoption.

Potential Risks, Privacy and Confidentiality: Although this research will not identify you by name, responses will be identified by your general role in the mining industry and geographic location (i.e., Ontario mining company respondent, Ontario mining supply and services respondent, Ontario technology company respondent, Ontario non-for-profit mining industry respondent, or Ontario government respondent). There is the possibility that due to your particular role, an individual might be able to ascertain your participation in this research. As a result, we cannot guarantee complete anonymity and there is minimal risk to participate in this study.

There are several open-ended questions that ask if you would like to provide more information. If you choose to answer these questions, anonymous quotations will be used in this research and identified by your general role and geographic location in the mining industry (e.g. Ontario mining company respondent). If you would prefer not to have anonymous quotations used in this research, you can decline to answer those questions.

You will be completing the study by an online survey operated by Qualtrics. Qualtrics has implemented technical, administrative, and physical safeguards to protect the information provided via the Services from loss, misuse, and unauthorized access, disclosure, alteration, or destruction. However, no Internet transmission is ever fully secure or error free. Please Note: We do not collect or use internet protocol (IP) addresses or other information which could link your participation to your computer or electronic device.

The data, with no personal identifiers, collected from this study will be maintained on a password-protected computer and secure server. As well, the data will be electronically archived after completion of the study and maintained for a minimum of seven years and then erased. The results of this research will be published in standard academic outlets such as graduate student theses, books and journals articles, as well as in policy briefs and reports, and in community presentations and reports.

Funding: This research is funded by the Ontario Government Scholarship (OGS) Program as well as the Social Sciences and Humanities Research Council (SSHRC) and the Early Researcher Award Program through the Ontario Government.

Ethical Approval: This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (REB #44089). If you have questions for the Board, contact the Office of Research Ethics at 1-519-888-4567 ext. 36005 or reb@uwaterloo.ca.

Questions, comments, or concerns: For all other questions or comments about the study, please contact Mackenzie Crabbe at mcrabbe@uwaterloo.ca or my supervisor Dr. Heather Hall at h.hall@uwaterloo.ca

Thank you for considering participation in this study.

Consent to Participant

By agreeing to participate in the study you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.

[insert check box or radio button] "I agree to participate."

[insert check box or radio button] "I do not wish to participate (please close your web browser now)."

Appendix C

<u>Email Invitation to Participate</u>

Subject Heading: Exploring Technology Adoption in the Mineral Mining Industry in Canada

Dear [insert name],

My name is Mackenzie Crabbe, and I am a Graduate Student at the University of Waterloo. I am administering a survey for my master's research study entitled "Exploring Technology Adoption in the Mineral Mining Industry in Canada", supervised by Dr. Heather Hall, University of Waterloo. The purpose of this research is to explore the drivers, enablers, and barriers to technology adoption in the mining sector in Canada (excluding Nunavut and NWT). Technologies might include autonomous equipment, autonomous operations, battery electric vehicles, sensors on equipment, 5G technologies, mapping technologies, drones, and artificial intelligence. This research is specific to the Canadian mineral mining industry and excludes oil and gas mining. This research study is also part of a larger, national research study entitled Remote Controlled: Technology in the Mining Sector and the Future of Development in Rural and Northern Regions led by Dr. Heather Hall. Summaries of the data from this survey may be shared with the national research team to inform the broader project.

Given your role as [insert role], I feel that you are well suited to provide insight into this topic and I would like to invite you to participate in this research. If you decide to volunteer for this study, your participation will consist of response to a 25-question survey that will take approximately 15 minutes to complete. Survey questions focus on topics such as what emerging technologies are being adopted in the Canadian mining sector, and what factors enable the decision to adopt technologies. Your participation in this study is voluntary. Data from this survey may be shared with the research team for the national project.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board. However, the final decision about participation is yours.

If you are interested in participating, please click this link or contact mcrabbe@uwaterloo.ca for more information.

Sincerely,

Mackenzie Crabbe

Appendix D

<u>Information Email for Industry Associations</u>

Subject Heading – Newsletter or Email Information for Graduate Research on Mining

My name is Mackenzie Crabbe, and I am a Graduate Student at the University of Waterloo. I am administering a survey for my master's research study entitled "Exploring Technology Adoption in the Mineral Mining Industry in Canada", supervised by Dr. Heather Hall, University of Waterloo, and I was hoping it would be possible to include information about my survey in your newsletter or if you could circulate information about my survey via email to your membership.

The purpose of this research is to explore the drivers, enablers, and barriers to technology adoption in the mining sector in Canada (excluding Nunavut and NWT). Technologies might include autonomous equipment, autonomous operations, battery electric vehicles, sensors on equipment, 5G technologies, mapping technologies, drones, and artificial intelligence. This research is specific to the Canadian mineral mining industry and excludes oil and gas mining. This research study is also part of a larger, national research study entitled Remote Controlled: Technology in the Mining Sector and the Future of Development in Rural and Northern Regions led by Dr. Heather Hall. Summaries of the data from this survey may be shared with the national research team to inform the broader project.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board. However, the final decision about participation is yours.

Please let me know if it would be possible to include information about my survey in your newsletter or if you could circulate information about my survey via email to your membership and I will send you the information to include.

Sincerely,

Mackenzie Crabbe

Appendix E

<u>Recruitment Email for Industry Associations</u>

Subject Heading: Exploring Technology Adoption in the Mineral Mining Industry in Canada

Sent on behalf of Mackenzie Crabbe, MES Candidate, University of Waterloo

Mackenzie Crabbe, a Graduate Student at the University of Waterloo has launched a survey to explore the drivers, enablers, and barriers to technology adoption in the mining sector in Canada. Technologies might include autonomous equipment, autonomous operations, battery electric vehicles, sensors on equipment, 5G technologies, mapping technologies, drones, and artificial intelligence. This research is specific to the Canadian mineral mining industry and excludes oil and gas mining. This survey will be used to inform her master's thesis, entitled

Exploring Technology Adoption in the Mineral Mining Industry in Canada", supervised by Dr. Heather Hall, University of Waterloo. This research study is also part of a larger, national research study entitled Remote Controlled: Technology in the Mining Sector and the Future of Development in Rural and Northern Regions led by Dr. Heather Hall at the University of Waterloo. Summaries of the data from this survey may be shared with the national research team to inform the broader project.

If you are a representative from a mining company, mining supply and service company, non-profit mining industry organization, municipal, provincial or federal government, mining-related technology company in the Canadian mineral mining industry (excluding Nunavut and NWT) and are interested in participating, please click this link or contact mcrabbe@uwaterloo.ca for more information.

If you have already completed the survey linked above, thank you!

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board.

If you have any questions about the study, please contact Mackenzie Crabbe at mcrabbe@uwateroo.ca.

Sincerely,

Mackenzie Crabbe

MES Candidate

University of Waterloo

Appendix F

<u>Newsletter item to be sent by Mining Industry Associations:</u>

Mackenzie Crabbe, a Graduate Student at the University of Waterloo has launched a survey to explore the drivers, enablers, and barriers to technology adoption in the mining sector in Canada. This survey will be used to inform her master's thesis, entitled Exploring Technology Adoption in the Mineral Mining Industry in Canada, supervised by Dr. Heather Hall, University of Waterloo. This research study is also part of a larger, national research study entitled Remote Controlled: Technology in the Mining Sector and the Future of Development in Rural and Northern Regions led by Dr. Heather Hall. Summaries of the data from this survey may be shared with the national research team to inform the broader project. If you are a representative from a mining company, mining supply and service company, non-profit mining industry organization, municipal, provincial, or federal government, mining-related technology company in the Canadian mineral mining industry (excluding Nunavut and NWT and are interested in participating, please click the following link or contact mcrabbe@uwaterloo.ca for more information. This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board. If you have already completed the survey, thank you!

Survey link

Appendix G

Poster Flyer

PARTICIPANTS NEEDED

We are looking for **representatives from the Canadian mineral mining industry** (e.g., mining company, mining supply and service company, no-profit mining industry organization, municipal, provincial, or federal government, mining-related technology company – excluding Nunavut and NWT) to participate in a research study exploring the **drivers, enablers, and barriers to technology adoption** in the mining sector in Canada.

If you volunteer to be in this study, your participation will consist of a 25-question survey that will take approximately 15-minutes of your time to complete. If you are interested in completing the survey, please scan the following QR code.

For more information about this study, please contact:
Mackenzie Crabbe at mcrabbe@uwaterloo.ca

This study has been reviewed by and received ethics clearance through a University of Waterloo Research Ethics Board.