POLYTECHNIQUE MONTRÉAL

affiliée à l'Université de Montréal

Understanding the Control of Hazardous Energies on Machinery: Using Lockout and Alternative Methods in Organizations and Developing a Self-Audit Tool

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Thèse présentée en vue de l'obtention du diplôme de *Philosophiæ Doctor*

Génie industriel

Novembre 2019

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présentée par **Benyamin KARIMI**

en vue de l'obtention du diplôme de *Philosophiæ Doctor*

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DEDICATION

To engineers and safety professionals

ACKNOWLEDGEMENTS

Completing this Ph.D. journey was not possible without the support of many individuals. I would like to first express my sincere thanks to my supervisor Prof. Yuvin Chinniah and my co-supervisor Dr. Damien Burlet-Vienney for their guidance and support by sharing personal and professional experiences.

I would also like to thank my jury members, Prof. Daniel Imbeau, Prof. Gerard J. Gouw, and Prof. Fabiano Armellini for reviewing this dissertation and for their thoughtful comments.

I would like to express my gratitude to all the organizations that participated in this work, and all the people who have been dedicated their time to support me in collecting data.

I also acknowledge the NSERC (Natural Sciences and Engineering Research Council) and IRSST (Institut de recherche Robert-Sauvé en santé et en sécurité du travail) for funding this work.

I am so grateful to my mother for her moral support.

Finally and most importantly, I would like to heartily appreciate my wife Zara (Zara Farahnak). Words cannot express how grateful I am to her; for her full support and encouragement.

RÉSUMÉ

Au Canada, comme dans de nombreux pays, les normes nationales et les réglementations provinciales exigent que les travailleurs œuvrant dans la zone dangereuse d'une machine pendant une phase de non-production suivent une procédure spécifique pour contrôler des énergies dangereuses. Si les énergies dangereuses de la machine ne sont pas contrôlées, il y a un risque de dégagement d'énergie, de mise sous tension ou de démarrage inattendu entraînant par conséquent des blessures ou décès. La norme canadienne CSA Z460 et la réglementation québécoise RSST décrivent les exigences en matière de contrôle des énergies dangereuses, appelées cadenassage (*consignation ou lockout*), ainsi que des méthodes alternatives lorsque le cadenassage ne peut pas être utilisé. Le nombre élevé d'accidents liés aux lacunes au niveau du contrôle des énergies dangereuses sur les machines démontre que les entreprises ont des difficultés avec l'application de ces exigences. En outre, l'absence d'audits du cadenassage ou d'outils pour l'audit de cadenassage est une réalité très répandue, de sorte que l'application du cadenassage n'est souvent pas entièrement conforme aux normes et aux réglementations. Au Québec, où cette étude a eu lieu, quatre décès et 1000 accidents se produisent en moyenne chaque année, en raison de l'absence ou des manquements aux procédures de cadenassage. Il existe peu d'études sur l'application réelle du cadenassage et elles se limitent en général à un secteur d'activité spécifique. Les outils disponibles pour auditer le cadenassage sont, pour leur part, incomplets. Par conséquent, les objectifs de cette thèse sont les suivants: premièrement, comprendre comment les entreprises mettent en œuvre des programmes et procédures de cadenassage, et dans quelle mesure ces programmes et procédures sont conformes à la norme CSA Z460 et à la réglementation en vigueur; et deuxièmement, concevoir un outil d'autodiagnostic pour auditer l'application des procédures de cadenassage sur la base des connaissances générées dans la première partie de l'étude.

Pour atteindre le premier objectif, une étude terrain a été réalisée et un questionnaire complet (concernant le programme de cadenassage, l'application des procédures de cadenassage, les méthodes alternatives, la gestion des sous-traitants, la formation et l'audit / inspection) a été développé à cet effet. L'application du cadenassage et des méthodes alternatives a été étudiée dans 14 entreprises issues de divers secteurs d'activité du Québec par le biais d'une entrevue de

groupe, d'une analyse documentaire et d'une observation du site dans chaque entreprise. Cette étape de l'étude a révélé que les pratiques de cadenassage en vigueur dans les entreprises visitées étaient meilleures que celles décrites dans leur programme de cadenassage. Cependant, un écart important a été constaté entre l'application du cadenassage et des méthodes alternatives et les exigences de la norme CSA et de la réglementation RSST. Les insuffisances constatées incluent: (i) des programmes de cadenassage incomplets; (ii) les étapes manquantes dans les procédures générales de cadenassage; (iii) les travailleurs ne lisent pas les fiches de cadenassage; (iv) le manque de connaissances sur les méthodes alternatives et la réglementation; (v) utiliser des méthodes alternatives sans évaluation des risques; (vi) formation insuffisante pour les méthodes alternatives; (vii) absence de supervision et de coordination des sous-traitants; (viii) et le manque d'outils d'audit et de documentation des résultats d'audit. L'étude a également proposé des recommandations (ex. mesures correctives) pour remédier aux lacunes identifiées. De plus, l'étude a révélé la nécessité de clarifier la norme canadienne et la réglementation québécoise sur l'utilisation de méthodes alternatives au cadenassage dans les organisations.

Afin d'atteindre le deuxième objectif, un outil d'autodiagnostic pour auditer l'application des procédures de cadenassage sur des machines a été conçu sur la base des conclusions de l'étape précédente et des normes et réglementations en vigueur. Cet outil a été développé pour vérifier la préparation de cadenassage (ex. les conditions nécessaires) et aussi pour évaluer l'application des procédures de cadenassage. L'outil a ensuite été testé pour la validité du contenu via un panel d'experts et six entreprises du Québec. L'étude a démontré que le nouvel outil avait un indice de validité du contenu élevé, à la fois en termes d'indice de validité de contenu pour les éléments (I-CVI) et d'indice de validité de contenu pour l'outil (S-CVI). En outre, l'outil était facile à utiliser et son exhaustivité était suffisante pour contrôler l'application du cadenassage sur les machines par rapport aux exigences normatives et réglementaires. En effet, en utilisant cet outil, les organisations peuvent trouver et corriger les divergences dans l'application du cadenassage, améliorer les pratiques de cadenassage et garantir la sécurité des travailleurs.

Cette thèse présente pour la première fois une étude sur l'application du cadenassage sur les machines dans les entreprises de différents secteurs. De plus, la thèse propose pour la première fois un outil d'autodiagnostic pour auditer l'application du cadenassage.

ABSTRACT

In Canada, like many countries, the national standard and provincial regulations require that workers working in the hazardous area of a machine during the non-production phase of machinery follow a specific safety procedure to control hazardous energies. Failure to control hazardous energies poses a risk of the release of energies, unexpected energization or start-up of machines (or equipment), hence resulting in injury or death. The Canadian Standard CSA Z460 and Quebec regulation ROHS describe the requirements for, and provide guidance on, the control of hazardous energies that is referred to as lockout, and also as alternative methods when lockout is not applicable. However, the high number of accidents linked to failure to control hazardous energies on machinery shows that organizations have difficulty with the application of lockout arrangements or the use of alternative methods. Moreover, the absence of audits of lockout or the lack of tools for auditing lockout is prevalent, and thus the application of lockout is often not fully in compliance with standards and regulations. In Quebec, where this study took place, four deaths and 1000 accidents on average occur annually due to either poor or the absence of, lockout procedures. Few studies exist on the actual application of lockout, but those are limited to a specific sector. Additionally, audit tools for the application of lockout are incomplete. Therefore, the objectives of this thesis are: first, to understand how organizations implement hazardous energy control programs and procedures, and the extent to which they are in accordance with relevant standards and regulations; and second, to design a self-audit tool for the application of lockout procedures on machinery based on the findings from the previous step.

To attain the first objective, the qualitative study was conducted, and a comprehensive questionnaire (which is about the lockout program, application of lockout procedures, alternative methods, sub-contractor management, training, and audit/inspection) was developed. The application of lockout and alternative methods was studied in 14 organizations from different sector specialties in Quebec, through a group interview, document review and site observation in each organization. This step of the study demonstrated that the actual lockout practices in the organizations visited were better than what was described in their lockout programs. However, major gaps were found between the actual application of lockout/alternative methods within the organizations studied and the standard CSA Z460 and Quebec regulation ROHS requirements. The shortcomings found included: (i) incomplete lockout programs; (ii) missing steps in general

lockout procedures; (iii) neglecting to read the placards; (iv) lack of knowledge about alternative methods; (v) using alternative methods without risk assessment; (vi) poor training for alternative methods and lockout program; (vii) absence of supervision and coordination of subcontractors; (viii) and lack of audit tools and documentation of audit results. The study also proposed recommendations (e.g. corrective actions) for addressing identified shortcomings and gaps. Moreover, the study revealed a need for clarifications on the Canadian standard and Quebec regulation for using alternative methods to lockout in organizations.

In order to attain the second objective, a self-audit tool for the application of lockout procedures on machinery was designed based on the findings of the previous step, and the current standards and regulations. The self-audit tool was developed to verify the preparation of lockout (i.e. surrounding conditions and pre-requirements) and also to evaluate the application of lockout procedures. The tool was then tested for content validity through a panel of experts and qualitative feedback from six organizations in Quebec. The study showed that this novel tool had high content validity index scores in terms of both the content validity index for items (I-CVI) and the content validity index for the tool (S-CVI). Furthermore, the tool was easy to use and completeness of the tool were adequate to monitor and evaluate the application of lockout on machinery against the normative and regulatory requirements. Indeed, by using this tool, organizations can find and correct problems and shortcomings in the application of lockout, improve lockout practices, and ensure safety of workers.

This thesis presents the first study on the application of lockout and alternative methods on machinery in organizations across different industries. Moreover, the thesis is a pioneer in proposing a self-audit tool for the application of lockout.

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LIST OF SYMBOLS AND ABBREVIATIONS

ANSI	American National Standards Institute
AS	Australian Standard
BLS	Bureau of Labor Statistics
CNESST	Commission des normes, de l’équité, de la santé et de la sécurité du travail
CSA	Canadian Standard Association
CVI	Content Validity Index
DEU	Deutsche Eislauf-Union
EN	European Standards
HSE	Health and Safety Executive
I-CVI	Content Validity Index for Items
IEC	International Electrotechnical Commission
INRS	Institut National de Recherche et de Sécurité
IRSST	Institut de recherche Robert-Sauvé en santé et en sécurité du travail
ISO	International Organization for Standardization
NFPA	National Fire Protection Association
NORA	National Occupational Research Agenda
OHS	Occupational Health and Safety
OSHA	Occupational Safety and Health Administration
PPE	Personal Protective Equipment
PUWER	Provision and Use of Work Equipment Regulations
ROHS	Regulation Respecting Occupational Health and Safety
RSST	Règlement sur la santé et la sécurité du travail

S-CVI	Content Validity Index for Scale
SEMI	Semiconductor Equipment and Materials Institute
SMED	Single-Minute Exchange of Die
SS	Singapore Standards Council
SST	Santé et de la Sécurité au Travail

LIST OF APPENDICES

CHAPTER 1 INTRODUCTION

Exposure to different types of machinery hazards and hazardous energies (e.g. electrical, hydraulic, pneumatic, kinetic, potential, chemical, and thermal in nature) can result in injury or death (Chinniah, 2015). International standards and national regulations explain how to control hazardous energies in order that workers intervene safely on machinery. For example, the North American standards (i.e. CSA Z460 (2013) and ANSI/ASSE Z244.1 (2016)) and Quebec regulation (ROHS, 2017) explain the requirements for the control of hazardous energies on machinery as lockout or, failing that, other hazardous energy control methods (i.e. alternative methods). The control is essential to prevent the release of energy (unexpected energization) or the inadvertent start-up of an energy source during any non-production activities (e.g. installation, maintenance, troubleshooting, repairs, adjustments, set-up, production disruptions, cleaning, dismantling or repair of machinery). Lockout is defined as the installation of a lock, which has a unique key and only the authorized employee has access to it, on an energy-isolating device on machinery in accordance with a step-by-step procedure (i.e. general lockout procedure). The general lockout procedure requires: (i) preparation for shutdown, (ii) shutting down machine, equipment or process, (iii) isolating machine, equipment or process, (iv) application of lockout devices, (v) dissipating and controlling stored energy, (vi) verification of isolation (Chinniah & Burlet-Vienney, 2013; CSA Z460, 2013; Poisson & Chinniah, 2016; ROHS, 2017). On the other hand, applying lockout to a full zero energy state is impracticable in all situations. When lockout affects the tasks that are integral to the production process by design or traditional lockout prohibits the completion of specific tasks, for example, minor service or minor cleaning; alternative methods (e.g. electronically interlocked access, presence-sensing device, or other methods) can be used.

Moreover, organizations should establish a written hazardous energy control program (i.e. lockout program), which includes policies, procedures, and instructions in accordance with standards and regulations, for implementing lockout and alternative methods (ANSI/ASSE Z244.1, 2016; CSA Z460, 2013). The program should contain the following main elements: (i) hazardous energy sources, (ii) types of energy isolating devices, (iii) lockout materials and hardware, (iv) roles and responsibilities, (v) general lockout procedure; (vi) managing special cases (e.g. lockout removal and continuity of lockout); (vii) external services; (viii) risk assessment; (ix) alternative methods; (x) training, and (xi) audits/inspections (Burlet-Vienney et al., 2009; Chinniah, 2010; ANSI/ASSE Z244.1, 2016; CSA Z460, 2013; Poisson & Chinniah, 2015; ROHS, 2017).

The absence of or ineffective lockout is one of the main causes of machinery-related accidents (Martin & Black, 2015; Bulzacchelli et al., 2008; Chinniah, 2015; Ruff et al., 2011). To prevent thousands of occupational injuries and save hundreds of lives, lockout must be carried out in compliance with related OHS (occupational health and safety) standards and regulations. While standards and regulations (e.g. North American standards and regulations) explain how to determine and select the appropriate method (i.e. lockout, alternative methods or a combination of these) to control of hazardous energy, decision making is not always easy since legal requirements on the control of hazardous energies vary from country to country or from province to province (Chinniah et al. (2008). Additionally, due to the rapid growth of technology, the need for different methods and techniques (i.e. alternative methods) for safeguarding workers from the unexpected release of hazardous energy is inevitable (ANSI/ASSE Z244.1, 2016). Applying alternative methods entails consideration of other requirements [e.g. risk assessment] (Chinniah & Burlet-Vienney, 2013; CSA Z460, 2013; Poisson & Chinniah, 2016; ROHS, 2017) that can pose new challenges for organizations. Moreover, organizations must monitor and assess their lockout practices against the normative and regulatory requirements, and organization's expectations (Grund, 1995; Kelley, 2001; Johnson (1996). As such, the need for a valid and proper tool for audits of lockout is essential.

Despite the regulations and standards put in place to regulate the control of hazardous energies, failure to control hazardous energy is still one of the main causes of machinery-related fatal and serious injuries in North America (CNESST, 2016; OSHA, 2018). Thus, this raises the questions of how organizations apply lockout and alternative methods, to what extent they are in compliance with standards and regulations, and how organizations can tackle problems related to the control of hazardous energies.

This thesis aims at investigating the actual energy control (i.e. lockout and alternative methods) practices in different organizations through a robust method to find shortcomings and problems, and also at developing a valid and applicable self-audit tool (through a novel proposed approach) for monitoring and evaluating the application of lockout procedures. The study provides further clarification on the use of the Canadian standard and Quebec regulation in terms of using alternative methods to lockout. The originality of this work is to investigate and evaluate the application of lockout and alternative methods in the organizations, which are diverse in terms of industry, size, and machinery through a group interview (by means of a comprehensive questionnaire), document review and site observation in each organization. Moreover, designing a valid, usable and complete self-audit tool for the application of lockout, which is developed based on the gaps and shortcomings found from the organizations and the requirements of the North American standards and Quebec regulation, represents another originality of this research.

The rest of this dissertation is organized as follows: Chapter 2 reviews the literature concerning the control of hazardous energies: lockout and alternative methods; Chapter 3 describes the research objectives, process, and the methodology employed; Chapters 4 presents a study on the control of hazardous energy on machinery in organizations; Chapter 5 presents a study on understanding the use of alternative methods to lockout; Chapter 6 proposes a self-audit tool for the application of lockout. Chapters 4-6 present the fulfillment of the specific objectives of this thesis through the two articles published in Safety Science and one article published in Safety. Chapter 7 discusses the main findings of the dissertation, and finally, the conclusions of this research as well as limitations and recommendations for future research, are provided in Chapter 8.

CHAPTER 2 LITERATURE REVIEW

This chapter provides a comprehensive review of the control of hazardous energies on machinery as well as a review of audits of lockout. In this regard, section 2.1 presents the control of hazardous energies in standards and regulations. Section 2.2 presents a review of accidents associated with failure to control hazardous energies. Sections 2.3 to 2.8 provide, respectively, a literature survey of (i) hazardous energy control program (i.e. lockout program); (ii) application of lockout procedures; (iii) application of alternative methods (i.e. other methods to lockout); (iv) training in the control of hazardous energy; (v) audits/inspections of controlling hazardous energy; and (vi) facilitating factors in the control of hazardous energy. Finally, the literature gaps on the basis of the literature review are presented in Section 2.9.

2.1 Control of hazardous energies in standards and regulations

Workers performing a task that required access to moving parts of machinery must follow an approach to controlling hazardous energies. This is explained in standards and regulations as lockout generally when zero energy state must be verified before performing the task, and as alternative methods when the energy is required during performing the task. In most standards and regulations lockout is the primary method of hazardous energy control. The general lockout program and procedure were explained in Chapter 1. The process of the control of hazardous energy, including the application of lockout and alternative methods is presented in Figure 2-1. As shown in Figure 2-1, the hazardous energy program (i.e. lockout program) comprises the factors (e.g. audit, training, responsibilities, required devices, etc.) that are important in implementing the control of hazardous energies. The Figure also showed the steps of the application of lockout and alternative methods. For the application of lockout, lockout procedures must be prepared (in accordance with the general lockout procedure) for each machine, equipment or process so that the authorized employee (one who is trained on lockout) can implement lockout. The details about the lockout program and lockout procedures are explained in sections 2.3 and 2.4. Moreover, to apply alternative methods (as shown in Figure 2-1), risk assessment must be carried out in order to select and use proper methods. Risk assessment process and alternative methods are explained in sections 2.5.1 and 2.5.2.

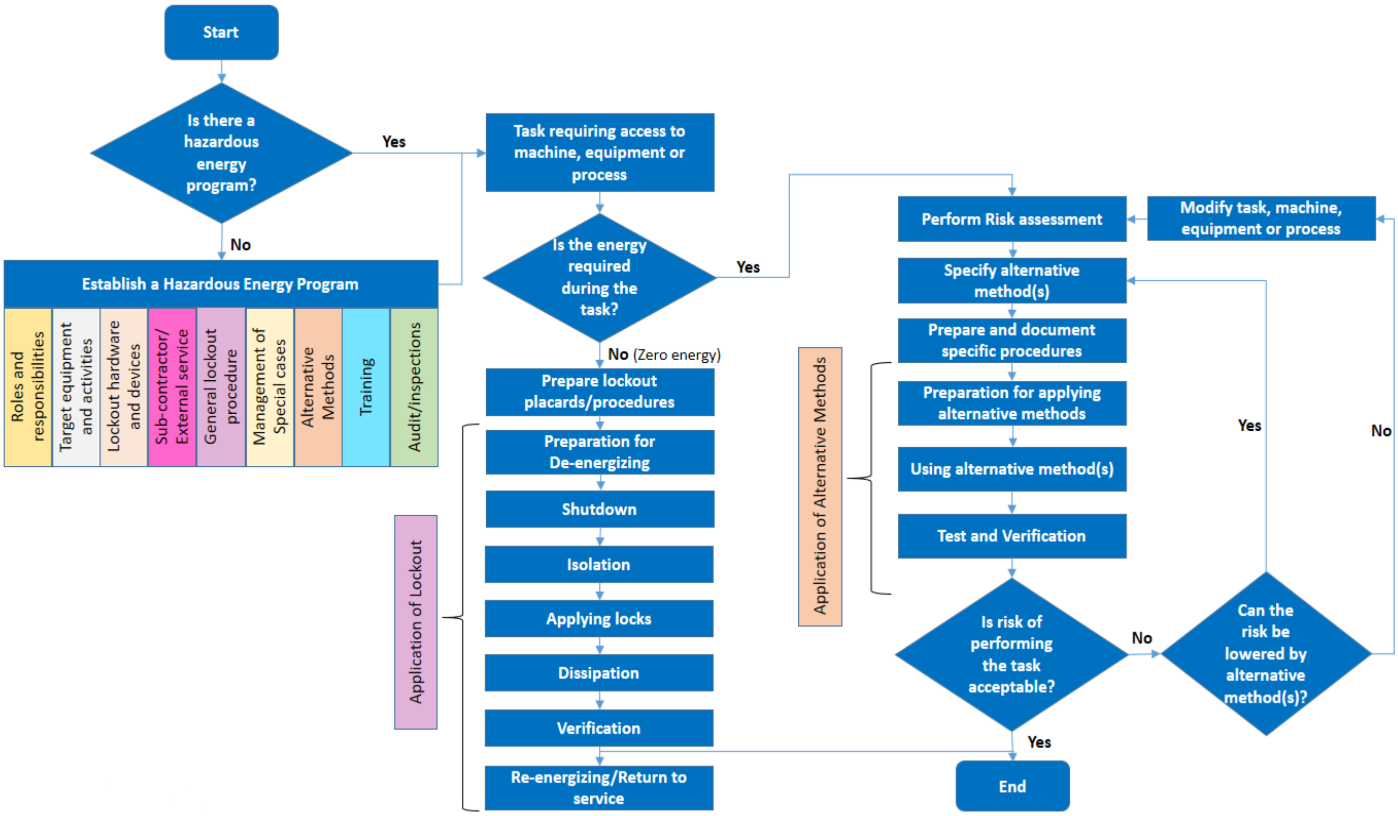

Figure 2-1 Control of hazardous energies: lockout and alternative methods (adapted from the standard ANSI/ASSE Z244.1 (2016))

2.1.1 North American standards and regulations

The American National Standards Institute [ANSI] (ANSI/ASSE Z244.1, 2016) and the Occupational Safety and Health Administration [OSHA] (OSHA 29 CFR 1910.147, 1989) in the U.S. explain the requirements for the control of hazardous energies, including lockout, tagout (i.e. install a tag on an energy-isolating device on machinery), and alternative methods. However, the standard provides more detailed information about the control of hazardous energy program and alternative methods. Both the standard and regulation have been the main references to define other nationwide standards or regulations.

In Canada, the Canadian Standards Association [CSA] (CSA Z460, 2013) describes the requirements of control of hazardous energies (i.e. lockout and alternative methods) in detail, and it is almost identical to the standard ANSI Z244. The Canadian standard is not mandatory in different provinces (including the province of Quebec), but it represents the state of the art in hazardous energy control. Moreover, in the province of Quebec, Quebec's Regulation respecting Occupational Health and Safety (ROHS, 2017) explains regulations on the control of hazardous energy. The regulations were updated and strengthened in 2016 (ROHS, Art. 188.1-13). The previous version of Quebec regulation had mentioned lockout as the only approach of controlling hazardous energies and without any explanation of what to do. Obligations are now in line with Canadian standard (CSA Z460, 2013), and American standard and regulation, i.e. ANSI/ASSE Z244.1 (2016) and OSHA 29 CFR 1910.147 (1989). This current regulation on the control of hazardous energy contains 13 sections: (i) definitions, (ii) the tasks in which hazardous energy needs to be controlled and the exemptions, (iii) energy control and hazardous area requirements, (iv) risk analysis, (v) developing written procedures (placards) and auditing them periodically, (vi) the contents of the lockout/alternative method procedures, (vii) the steps for controlling energy sources, (viii) training, (ix) the authorization to remove a padlock during the absence the person who installed it, (x) managing external services, (xi) keeping records of lockout (i.e. installation locks and the person responsible), (xii) the procedure for removing the padlock and (xiii) the link with the lockout of the electrical installations (Figure 2-2). In addition to these sections, the regulation explains the situation where lockout can be exempted or not be applied (i.e. Art. 189 and 189.1). All these standards and regulations above advise on alternative methods to lockout but in different ways.

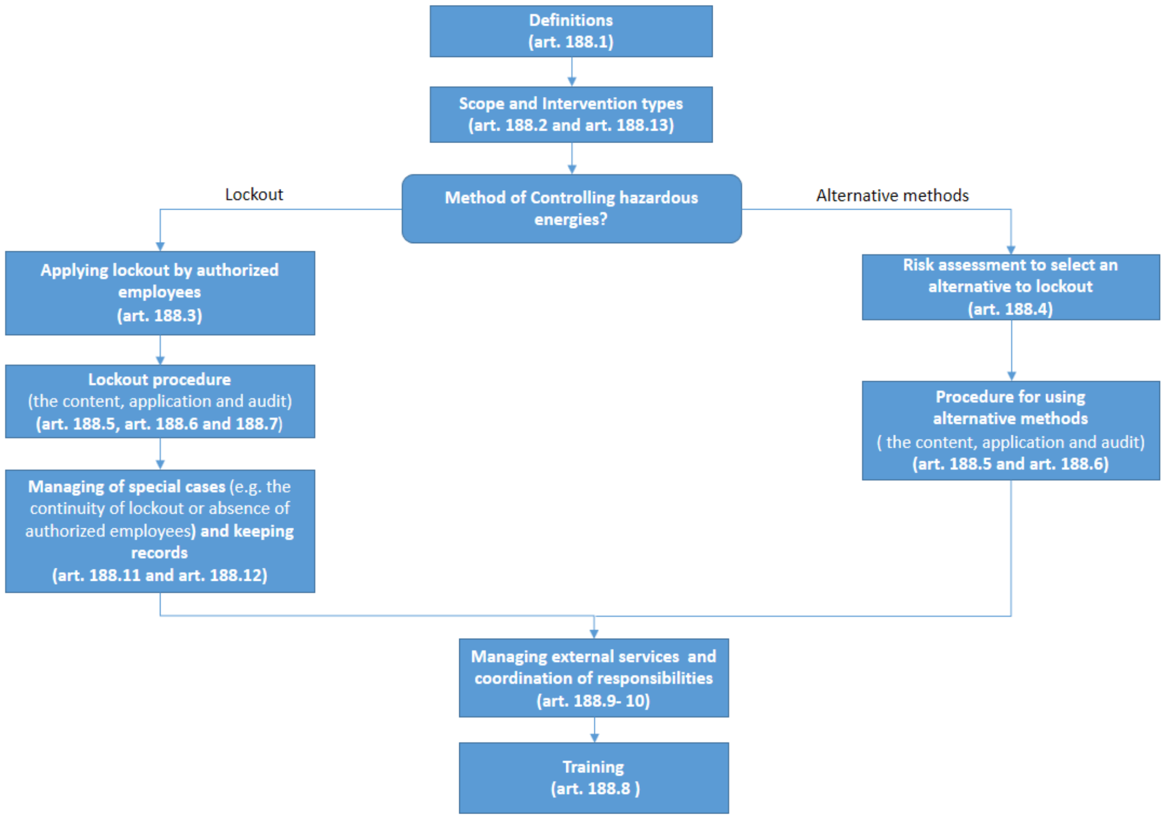

Figure 2-2 Structure and logic of the Quebec regulation (ROHS, 2017) concerning the section on lockout and other methods of energy control (adapted from Burlet-Vienney et al. (2017a)).

2.1.2 Other standards and regulations

The control of hazardous energy is also explained in worldwide standards like the international standard ISO 14118 (2017) and the European standard EN 1037:1995+A1 (2008) as well as in other nationwide regulations/standards such as the standard AS 4024.1603 (2006: R2014) in Australia; the standard SS 571 (2011) in Singapore; the PUWER (1998) regulation 19 in UK; the DEU (2015: R-101566) in Germany; and European directive European directive CEE 89/655 (1989). However, in comparison to standards, most regulations provide minimum requirements associated with the control of hazardous energy. For example, the standard SS 571 (2011), which is in line with North American standards (ANSI/ASSE Z244.1; CSA Z460), provides detailed information about the control of hazardous energy, while the European directive CEE 89/655 (1989) outlines minimum regulations. In additions to regulations and standards, guidelines (e.g. OSHA 3120 (2002) in the U.S. or PN10596 (2011 R:2019) in Australia) have been provided for controlling hazardous energies in some countries. To illustrate, the Institut National de Recherche et de Sécurité (INRS) in France published two best practice documents (i.e. ED 6109 and ED 6129). The first contains an isolation procedure that explains what and how lockout devices can be used for isolation and return to service purposes during interventions. The latter document comprises alternative methods for performing the operation safely when interventions without energy cannot be carried out (INRS, 2014; INRS, 2015).

A study by Chinniah et al. (2008) on worldwide standards and regulations showed that the concept of lockout had different meanings or definitions in the regulations while definitions of lockout in standards had certain similarities. The authors found that the requirements for the application of lockout varied in regulation to regulation in different countries and also identified some differences in the standards studied concerning the elements of lockout programs.

A brief comparison of some of these standards and regulations with regard to control hazardous energy is presented in Table 2-1. The table was adapted from Chinniah et al. (2008) and was also updated in terms of the standards and regulations. Table 2-1 presents whether the main factors in the control of hazardous energies (listed in each row) exist and are explained in the aforementioned standards and regulations (listed in each column). As shown in Table 2-1, the standards such as CSA Z460 (2013), ANSI/ASSE Z244.1 (2016), and SS 571 (2011) tend to have similar requirements, but, by contrast, AS 4024.1603 (2006: R2014), ISO 14118 (2017), and EN 1037:1995+A1 (2008) do not cover all the main factors in hazardous energy control, and also some discrepancies exist. The regulations (i.e. OSHA 29 CFR 1910.147 (1989) and ROHS (2017)) cover almost all the requirements. However, by comparison with the North American standard (i.e. CSA Z460 and ANSI Z244.1), these regulations provide less information about the control of hazardous energies.

Table 2-1 Control of hazardous energies in standards and regulations (adapted from Chinniah et al. (2008))

Main factors in hazardous energy control	**Standards and Regulations**							
	CSA Z460 (2013)	ANSI Z244.1 (2016)	SS 571 (2011)	AS 4024.1603-2006 (R2014)	ISO 14118 (2017)	EN 1037+A1 (2008)	OSHA 29 CFR 1910.147 (1989)	Quebec's ROHS (2017)
Scope (machine/equipment/process)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Energy type and isolating devices	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Energy control procedure (de-energizing)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Return to service procedure (re-energizing)	Yes	Yes	Yes	No	No	No	Yes	Yes
Management of special cases (e.g. continuity of lockout and absence of authorized workers)	Yes	Yes	Yes	No	No	No	Yes	Yes
Sub-contracting/External services	Yes	Yes	Yes	No	No	No	Yes	Yes
Training	Yes	Yes	Yes	No	No	No	Yes	Yes
Alternative methods	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Risk assessment	Yes	Yes	Yes	No	Yes	No	No	Yes
Application of alternative method procedures	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Audit of the program	Yes	Yes	Yes	No	No	No	No	No
Audit of the application of procedures	Yes	Yes	Yes	No	No	No	Yes	Yes

In summary, standards and regulations address organizations' concerns in order to determine which method (i.e. lockout, alternative methods or a combination of these) is proper to control hazardous energy as well as to describe the conditions surrounding alternative methods. Nevertheless, decision making is not always easy since the standards and regulations provide no identical guidelines, and thus interpretation can be very subjective. Taking the above into consideration, the control of hazardous energy is not only an issue in North America but also worldwide.

2.2 Accidents associated with failure to control hazardous energies

Contact with moving parts of machinery where workers intervene in the non-production phase of a machine (i.e. installation, operation, maintenance, troubleshooting, repairs, adjustments, set-up, production disruptions, cleaning, and dismantling) can induce serious injuries or fatalities (Chinniah, 2015; Yamin et al., 2016). The U.S. Bureau of Labor Statistics (BLS) revealed that a total of 723 fatal work injuries (approximately 14% of total fatalities) annually occurred owing to contact with objects and equipment in the period 2015-2018 (BLS, 2018).

Contact with moving parts of machinery was the main cause of 500 fatal accidents (approximately 29% of total fatalities) that occurred annually in Netherland (Bellamy et al., 2007). Likewise, the UK Health and Safety Executive (HSE) revealed that in the period 2013-2017, 22% of total fatal work injuries annually happened as a result of contact with and struck by moving objects (HSE, 2018). These serious injuries and fatalities can be as a consequence of, for example, the release of hazardous energies, unexpected energization or start-up of machines or equipment.

For example, Chinniah (2015) analyzed 106 accidents involving moving parts of machinery in the province of Quebec (Canada) and showed that several accidents happen during maintenance or during production activities when the operator entered the dangerous zone of the machine where mechanical hazards were present. The study found that 12.3% of accidents were related to the machine set-up phase of machinery, 19.8% of accidents were during production tasks, 34.9% of accidents were during maintenance tasks and 31.1% were linked to dealing with production disturbance (e.g. unjamming). The author showed that the main causes of machinery-related accidents were easy access to moving parts of machinery, lack of proper safeguards, inexperienced workers, circumvention of safeguards, absence of risk assessment, lack of supervision, poor machinery design, unsafe methods of working, absence of clear instructions linked to control systems, and absence of lockout procedures. Indeed, the study showed that in 33 accidents companies have no lockout programs and lockout procedures were not used during maintenance, repairs, and unjamming activities. In 21 accidents, lockout programs existed, but lockout procedures were not used during maintenance, repairs and unjamming activities. In two accidents, whereas lockout programs existed, there were no lockout procedures (placards) for the machinery. The study identified the main causes of these types of accidents were: (i) absence of using lockout procedure; and (ii) incomplete or incorrect lockout procedure accidents. Similarly, the absence of or deficient lockout procedures, as one of the main causes of serious and fatal accidents, is found in studies on the analysis of machinery related accidents in the U.S. (Bulzacchelli et al., 2008; Martin & Black, 2015; Ruff et al., 2011), UK (Shaw, 2010), France (Blaise & Welitz, 2010), and Netherlands (Aneziris et al., 2013).

Furthermore, according to the OSHA, lockout was the fifth most cited OSHA violation in the period 2015-2018. For example, during 2017 and 2018, 3,131 and 2,944 citations, respectively, were issued for violations of the lockout/tagout standard OSHA 29 CFR 1910.147 (OSHA, 2017; OSHA, 2018). The lack of documented lockout procedures, the absence of periodical inspections, absence of a lockout program, lack of training for authorized employees, and neglect of notifying affected employees during the application of lockout were the most-cited sections in the lockout/tagout standard (OSHA, 2017; OSHA, 2018). Likewise, in the province of Quebec (Canada) on average, 10% of fatalities occurred annually due to poor or absent lockout procedures (CNESST, 2016). In Ontario (Canada), 17 % of orders issued by the Ontario Ministry of Labor to employers during 2013 were due to violations of lockout and machine guarding (Ontario Ministry of Labor, 2016).

Blaise and Welitz (2010) analyzed 88 accidents, which were linked to machinery during non-production phases (i.e. maintenance), occurring between 1998 and 2007 in France. The authors found that 69% of accidents were connected mainly to incomplete isolation/lockout procedures. Lind (2008) analyzed 33 Finnish accident reports of severe injuries and fatalities related to industrial maintenance. The author showed that organizational factors and unsafe actions (lockout method) were the main causes of serious and fatal accidents. Bulzacchelli et al. (2008) reviewed 592 lockout/tagout-related incidents that caused a total of 624 fatalities in the U.S. The study showed that in the most of cases (70%), absence of the application of lockout procedures were found. In a few incidents despite the attempt to apply lockout, a fatality occurred owing to human error (5.2%) or mechanical failure (1.2%). Shaw (2010) reviewed 100 incident investigation reports in the UK in the period 2002-2007 and revealed that failures to isolate (lockout) were major causes of the accidents. Martin and Black (2015) analyzed 457 incident reports from six multinational organizations in different industries. The authors found that incidents with the potential to result in serious injuries and fatalities had a strong connection to deficiencies in management systems related to lifesaving policies, programs (e.g. lockout, machine guarding and barricades, etc.) and risk assessment. The study indicated that serious or fatal accidents occur during routine operation/production or maintenance/repair tasks when these management systems are either absent, ineffective, or not compliant with.

2.3 Hazardous energy control program (i.e. lockout program)

As mentioned in chapter one (Introduction), lockout program is the document that establishes the company's general policies and instructions for implementing lockout and provides the instruction for regulatory compliance and it is obligatory in some regulations and standards. In 2009, a guide including listing main elements which need to be considered when preparing a lockout program was published (Burlet-Vienney et al., 2009). The main elements of a lockout program in the guide were as follows: (i) roles and responsibilities; (ii) audit; (iii) training; (iv) communication; (v) hazardous energy sources; (vi) equipment design characteristics; (vii) lockout hardware; (viii) lockout hardware utilization principles; (ix) target activities and work; (x) general lockout procedure; (xi) lockout of equipment in the immediate surroundings; (xii) general return-to-service procedure; (xiii) general lockout placard; (xiv) continuity of lockout; (xv) case of absence of the authorized individual; (xvi) external services or subcontractors. In addition to those elements, risk assessment and alternative methods should be considered when drafting a lockout program (ANSI/ASSE Z244.1, 2016; CSA Z460, 2013). The North American standards and regulations require that companies prepare instructions (described in the lockout program) for managing especial cases such as the absence of an authorized employee (specially when a padlock must be removed), and the continuity of during shift changes or forgotten/losing key). They also require that in the case of the outsourcing a task that was carried out by external employees (i.e. subcontractors), the determination of roles and responsibilities, coordination and communication between them and local employees must be described in the lockout program.

The online guideline for hazardous energy control NORA (2018) states that a successful program contains four main activities: (i) energy control procedures; (ii) employee training; (iii) audits and periodic inspections; and (iv) lockout equipment and devices. Johnson (1996) mentioned that if the elements of the program are unclear or outdated (not accordance with the company expectation), then the program will not be applicable or enforced. Kelley (2001) indicated that a lockout program required the participation of employees during its development in order to be more efficient and complete.

A review of lockout programs in 31 companies in the province of Quebec showed that most of the lockout programs were not fully compliant with the regulation and standard (Chinniah, 2010). The author showed that, for example, important elements such as the design characteristics of new or upgraded equipment were missing. Additionally, alternatives to lockout, training, and program application review were absent in many written lockout programs. The study showed that lockout programs obtained from large companies lacked fewer elements than those obtained from small companies (Chinniah, 2010). Similarly, Parker et al. (2015b) showed written lockout programs were more available and complete in larger companies (in terms of the number of employees) that had safety committees.

A study by Chinniah and Burlet-Vienney (2013) on developing a lockout program for the municipal sector in Quebec (21 municipal sites equipped with fixed and mobile equipment), showed that the programs were not drafted or incomplete in most municipalities. Poisson and Chinniah (2015, 2016) conducted a study on lockout programs in eight sawmills in Quebec. The authors mentioned that, although lockout programs were essential parts of lockout implementation in the sawmills, they were used more as the means of regulatory compliance than as prevention tools. The lockout program needs to be improved regarding the general lockout and return to service procedures. There were no date and signature found on lockout programs and indeed they were outdated and did not cover the requirement of the standard. The missing elements in most programs were: (i) role and responsibilities; (ii) audit; (iii) equipment design characteristics (iv) alternative methods (v) lockout hardware and utilization principles. The authors demonstrated that workers had little understanding of the documents (i.e. written lockout programs), and the lockout programs did not reflect the actual practice of the workers' interventions on machinery. The study by Chinniah (2015) revealed that having a lockout program does not infer that lockout procedures are being used. In other words, the lockout program is not always an accurate measure of the actual lockout practice.

2.4 Application of lockout procedures

The North American standards and regulations provide a step-by-step approach to controlling hazardous energies (i.e. the general lockout procedure) that must be followed by authorized employees. The general lockout procedure comprises four steps: (i) preparation for shutdown, (ii) shutting down machine, equipment or process, (iii) isolating machine, equipment or process, (iv) application of lockout devices/material, (v) dissipating and controlling stored energy (de-energization), (vi) verification of isolation (start-up test or using measuring instruments (Chinniah & Burlet-Vienney, 2013; CSA Z460, 2013; Poisson & Chinniah, 2016; ROHS, 2017). According to the standard CSA and Quebec regulation ROHS, a specific lockout procedure/ placard must be prepared (based on the general lockout procedure) for each machine, equipment or process so that the authorized employees (who are trained on lockout) and external employees (sub-contractors) follow it to apply lockout properly and ultimately the related task (repair, service, maintenance, etc.) can be done safely. These procedures should be easily accessible to workers (i.e. authorized employees). A study by Parker et al. (2015a) on safety programs (including lockout/tagout and safeguards) in 221 small metal fabrication businesses in the U.S. showed that lockout procedures were posted on machines in only 9% of workstations. Bulzacchelli et al. (2008) stated that understanding problems in following the lockout/tagout procedures and finding ways to raise the use of them are important for preventing serious injuries and fatalities. Rutter (2005) stated that the use of placard with photos of energy isolating devices may be preferred to allow the worker to locate the exact location to padlock, and also the identification of the equipment with a number can simplify the procedure. Campbell (2003) argued that a wrong procedure is more dangerous than the absence of a procedure because the workers who follow a procedure rely on the instructions and may thus reduce their vigilance. Poisson and Chinniah (2016) recommended simplifying lockout procedures, thereby decreasing the time spent on them, and reducing the incentive to defeat them.

Poisson and Chinniah (2015, 2016) showed the absence of lockout procedures for some types of machinery as well as the difficulties in following lockout procedures in sawmills. They found that workers did not carry out the verification step in the general procedure during the application of lockout, and also return to service steps were carried out without notifying workers to ensure that nobody was in the danger zones of machinery. Moreover, the study showed that lockout placards were not read by workers (mostly experienced workers), especially when isolating only one or two energy sources. The authors mentioned that it is problematic since the risk with such a practice can be high when, for example, switching off the wrong isolating device and not doing the verification step, or when some changes made in the machinery and workers are unaware of. Parker et al. (2016) evaluated lockout/tagout (i.e. the presence of program, procedures and isolation devices) in 160 small metal fabrication firms through baseline evaluation, two intervention visits (proposing the recommendations to shops), and a follow-up (12-month). The study found that only 8% of the total firms had lockout procedures at the beginning of the study. The authors showed that improvement in (i) the presence of lockout procedures from 8% to 33%; (ii) the development of a lockout program (by the company) from 55% to 76%; and (iii) the presence of lockable disconnects by 92% compared to 88%.

2.5 Application of alternative methods

In the following sub-sections, a review of the literature on risk assessment, which must be carried out before using alternative methods, and applying alternative methods are presented.

2.5.1 Risk assessment

The North American standards (ANSI/ASSE Z244.1; CSA Z460) and Quebec regulation (ROHS) require implementing risk assessment before applying alternative methods. To illustrate, the Quebec regulation requires that employers who intend to apply an energy control method other than lockout, must first ensure the equivalent safety of that method by analyzing the following: (i) the machine features; (ii) identification of the health and safety risks when using the machine; (iii) an estimate of the frequency and seriousness of the potential employment injuries for each risk identified; (iv) the description of prevention measures that apply for each risk identified; (v) the estimate of the level of risk reduction obtained and the assessment of residual risks; (vi) documentation of the results of the analysis (which must be recorded in a written document). Chinniah (2015) showed that a lack of risk assessment (or job hazard analysis) was one of the main causes of fatal accidents related to machinery.

ISO 12100 (2010) explains that the risk assessment process comprises risk analysis and risk evaluation (as shown in Figure 2-3). Risk analysis is a combination of (i) the specification of the limits of the machine, (ii) hazard identification and (iii) risk estimation. The risk estimation is carried out for each hazardous situation (by means of defining likely severity of harm and the probability of its occurrence) to provide information on the level of risk. Finally, risk evaluation is to make a judgment, based on the results of risk estimation, about whether the risk reduction objectives are achieved. Furthermore, some standards and studies present a method for risk assessment (Aneziris et al., 2013; Chinniah et al., 2011; Etherton et al., 2008; Gauthier et al., 2012; CSA Z1002, 2012; ANSI/ASSE Z10, 2012; ISO/IEC 31010, 2009; ISO 12100, 2010; ANSI B11.0, 2015).

Manuele (2005) mentioned that the process of determination of the severity of harm and the likelihood of occurrence is subjective and is carried out based on the knowledge of the people. Therefore, risk assessment is a subjective process and given that, ranking risks is also subjective. It should be mentioned that a risk estimation tool does not give an absolute value of a risk. Regardless of the methods used (e.g. matrix, checklist, risk graph), there will always be uncertainties related, for example (i) to the parameters used, (ii) to the model chosen, and (iii) to the completeness of the factors considered (Abrahamsson, 2002). Cox Jr (2008) and Duijm (2015) summarized the main criticisms associated with risk matrixes (e.g. subjective classification, limited resolution, and effectiveness). Chinniah et al. (2011) also listed recommendations for the construction of such tools (e.g. number of levels per parameter, definition of parameter levels, relative influence of each parameter, uniform distribution of levels).

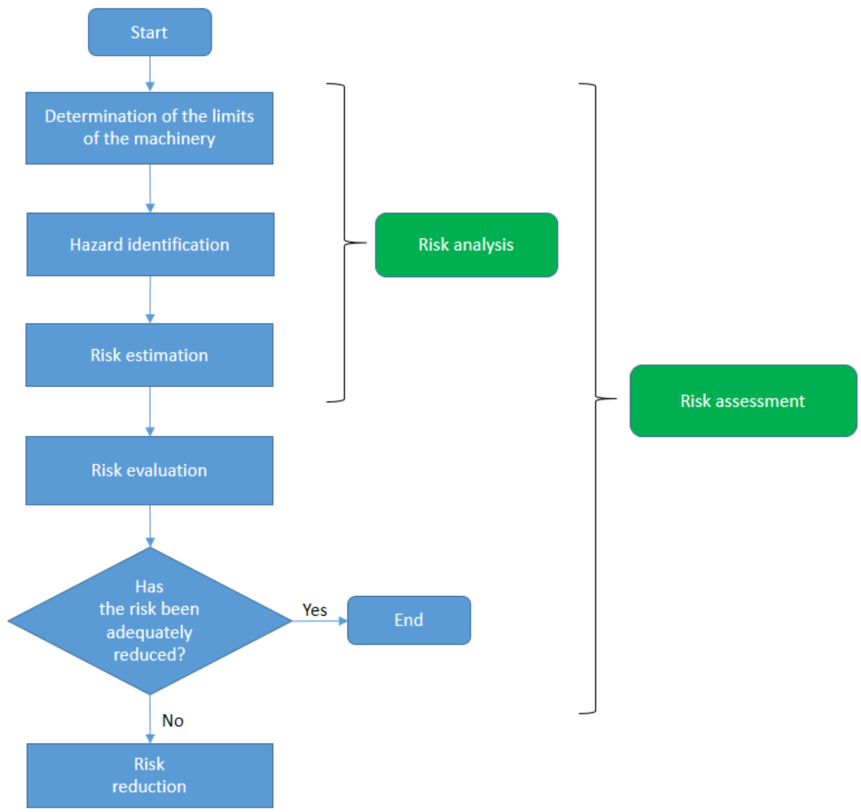

Figure 2-3 Risk assessment and reduction process according to the standard ISO 12100 (2010)

Furthermore, as Figure 2-3 shows, if risk is unacceptable, then the process of risk reduction must be performed and risk must be reassessed and repeated. Indeed, implementing the risk reduction process is based on the results of the process of risk assessment. A hierarchical process shall be used in the selection of feasible risk reduction measures in the following order of preference: (i) eliminate the hazard through design or substitution; (ii) engineered safeguards and safeguarding devices (e.g. fixed guards, moveable guards with interlock, presence sensing devices, two-hand control devices and etc.); (iii) awareness devices and alerting techniques; (iv) safe work procedures and training; and (v) use of personal protective equipment (PPE) (Chinniah et al., 2007; Manuele, 2005; ANSI B11-TR3, 2000; CSA Z432, 2016; ISO 12100, 2010; Zoubek, 2015). However, Caputo et al. (2013) showed that in order for effective protection, the adequacy of a safety measure or selecting between the two measures is based on the analyst' opinion and personal judgment.

In summary, selecting alternative methods to control hazardous energy will be based on the output of the risk reduction process, and for this reason, risk assessment is a vital process. However, uncertainty in risk assessment might produce an adverse effect on the effectiveness of alternative methods. The effectiveness of alternative measures was discussed in the literature (Backström & Döös, 2000; Booth, 1979; Caputo et al., 2013; ANSI/ASSE Z244.1, 2016; Gauthier & Charron, 2002).

2.5.2 Alternative methods

To apply alternative methods, the Canadian standard, CSA Z460 (2013) explains that appropriate tasks (to be considered integral to production) for other control methods shall exhibit most of the following characteristics: (i) of short duration; (ii) relatively minor in nature; (iii) occurring frequently during the shift or production day; (iv) usually performed by operators, set-up persons, and maintenance personnel; (v) represent predetermined cyclical activities; (vi) minimally interrupt the operation of the production process; (vii) exist even when optimal operating levels are achieved; and (viii) require task-specific personnel training (CSA Z460, 2013). Moreover, in Quebec, regulations on lockout ROHS (2017) explains lockout is the preferred method, but using alternative methods through a risk assessment (that ensures equivalent safety) is now possible when lockout cannot be applied. The articles 188.2 and 189.1 of the regulation explain that lockout is exempted where the machine is equipped with a specific control mode and that allows the machine to only be operated, for example, by using a control device requiring continuous action/a two-hand control device, or at reduced speed/under reduced tension [i.e. by using these alternative methods] (ROHS, 2017). Electronically interlocked access, trapped key system, presence-sensing device or remote lockout can be relevant alternatives to lockout (Burlet-Vienney et al., 2017b).

A qualitative study on the application of the Quebec regulation specifically article 189.1 was carried out at 15 machines in nine companies (Chinniah et al., 2017a). The study showed that companies had difficulties in applying this article of the regulation due to (i) some machines needed to be adapted on site based on the requirements of the article; (ii) workers who performed the tasks in the danger zone did not use a hold-to-run control or an inching/jogging advance mode; (iii) low level of workers’ knowledge; and (iv) the poor explanation of the article in the regulation; (v) a lack of risk assessment. The authors also proposed recommendations for users and designers in order to use reduced-energy modes of operation, especially in terms of the determination of the most appropriate values for reduced speed, force, pressure, and temperature.

Similar to lockout procedures, both the standard and regulation require that organizations provide procedures (or instructions) for applying alternative methods similar to lockout procedures. For example, Quebec regulation explains the steps of the general procedure for an alternative method as follows: (i) identification of the machine/equipment; (ii) identification of the person responsible for the energy control method; (iii) identification and location of every control device and of every energy source of the machine; (iv) identification and location of every cut-off point of every energy source of the machine; (v) the type and quantity of material required for applying the method; (vi) the steps required to control the energy; (vii) where applicable, the measures designed to ensure the continuity of application of the energy control method during a staff rotation, in particular, the transfer of required material; and (viii) where applicable, the applicable characteristics, such as the release of residual or stored energy, the required personal protective equipment or any other complementary protection measure (ROHS, 2017).

Poisson and Chinniah (2016) demonstrated that the alternative methods used in sawmills were not fully compliant with Canadian standard and Quebec regulation. The authors found: (i) permits as alternative methods were issued without a risk assessment for troubleshooting activities; (ii) whereas special tools (e.g., a gaff to unjam logs on conveyors or a belt as PPE) were used for situations that lockout was not feasible, risk assessment was not applied; (iii) absence of an electrical interlocking system to stop the machine when guards were opened; and (iv) absence of written procedures or instructions for alternative methods used.

Burlet-Vienney et al. (2017b) showed that although the main procedure for major tasks on mobile equipment should be lockout, it is important to identify types of work that will require a specific position for the equipment (e.g., raised bed), a specific energy source (e.g., for diagnostic purposes) or a specific procedure. Maintenance or service of this kind will require alternative methods. The authors also indicated that an alternative method for mobile equipment after risk assessment may apply to the following situations: (i) a need for an energy source to perform a task, such as diagnostic and verification steps, in the hazardous zone. In these situations, it may be necessary for some parts of the equipment to be in motion when a worker is nearby; (ii) short duration and minor tasks in or outside of a workshop or garage. Inside a workshop or garage, it refers to the tasks such as changing windshield wiper blades, replacing headlight bulbs and conducting visual inspections. Out of a workshop or garage, it refers to the tasks that must be done to allow the machine to continue operating, such as unjamming or doing minor repairs. This is the case in particular for snow blower mechanisms (e.g., a drum or auger) that can get jammed several times during a shift. Besides, for minor repair activities where only one worker is involved, a safe shutdown with control of the ignition key and the display of work-in-progress signs may be sufficient.

Kay and Schuster (2018) concluded that effective alternative methods, which are compliant with standards and regulations, can improve both the safety and productivity of related operations in the forest industry. The authors stated that alternative methods can decrease the likelihood of bypassing (that is usually found in the application of lockout), reduce the needed time for maintenance tasks, and ultimately improve productivity.

2.6 Training

The standard CSA Z460 (2013) and Quebec regulation ROHS (2017) require that all authorized employees as well as affected employees (who are not directly involved in the work but located in the work area) must be trained before applying energy control methods (i.e. lockout or alternative methods). In addition to these employees, outside employees (i.e. external services or subcontractors) should receive training. The standard CSA Z460 explains that training must enable employees to implement all the steps of procedures for lockout and alternative methods. According to this standard, training on the control of hazardous energy must be a part of a lockout program (i.e. hazardous energy control) and must include (i) samples of machine-specific procedures (ii) the type and magnitude of the energy available in the workplace (iii) means to control and isolate energy and verify its controlled state. Furthermore, the standard requires periodic refresher training for authorized employees since training it is not a one-off action. It must be conducted at intervals not to exceed three years, to maintain an appropriate level of the worker’s knowledge. The content of this refresher training must be based on hazards and risk assessment for the task and working conditions. Training and re-training records of all employees must be kept and documented. According to the standard, outside employees should be trained and possess the applicable qualifications to perform work covered by this Standard (CSA Z460, clause 7.3.6)

Additionally, Rutter (2005) noted that workers must be trained for specific tasks so that they can: (i) recognize sources of energy at risk, (ii) understand the type and power of energy; (iii) know the methods for isolating and controlling dangerous energies; and (iv) know the methods for neutralizing energies safely. Johnson (1996) mentioned that training must be based on the realities of enterprises and complex procedures. Wallace (2007) recommended that both groups of authorized and affected employees should receive training in lockout.

Kelley (2001) found that training/ retraining was an important factor in applying lockout. A study by Demirkesen and Arditi (2015) showed that the important factors in safety training were the use of visual aids, providing feedback from workers, and training assessment. In terms of the importance of the practical training, Ray et al. (1997) noticed an improvement in the safety behavior of participants (in the workplace) when feedback was provided and added in the training program.

2.7 Audit/Inspections

Audit is a systematic process to evaluate objective evidence against audit criteria through internal or external sources. Audits and specifically internal audits (which are carried out by organizations and internal auditors) help organizations determine whether their occupational health and safety (OHS) management systems are effectively implemented in compliance with standards (ISO 19011, 2018; ISO 45001, 2018). In the following sub-sections, a literature survey of the audits of controlling hazardous energies, and proper tools for audits are presented.

2.7.1 Audit of controlling hazardous energies

Audits of lockout can comprise the audit of lockout program (i.e. the elements of lockout program) and the audits of the application of lockout (or alternative method) procedures. According to the standard CSA Z460 (2013), auditing of the program elements should be conducted frequency and shall be at regular intervals of three years or less. Moreover, the employer shall be responsible for conducting the auditing plan (e.g. at least annually) through visual observations of authorized individuals (employees) implementing specific lockout procedures, to correct any observed deviations or inadequacies. The Quebec regulation (ROHS, art. 188.5) explains procedures must be reviewed periodically, in particular, every time a machine is altered or any problem is reported, so as to ensure that the energy control method remains efficient and safe. Additionally, the Quebec regulation (art. 188.9) requires that employers provide supervision and monitoring of the subcontractor's activities to ensure that self-employed worker will apply an energy control method that complies with the regulation (ROHS, art. 188.9). Despite all these requirements, there is no proposed audit tool for lockout in the standard or regulation.

Grund (1995) stated that the monitoring of the application of lockout is important to ensure that: (i) the lockout procedures are adequate, effective and used; and (ii) employees are trained to react to unusual situations by avoiding the improvisation of a dangerous, temporary and rapid work method. The author mentioned that the absence of incidents for several months or years does not automatically indicate that padlocking is properly applied. Employees may not use lockout and have developed practices exposing them to dangerous energies. Audits allow companies to evaluate lockout and make realistic portraits of actual practices, to identify the problems and to correct them. Furthermore, audits allow a continuous improvement of the lockout practice. According to Grund's study audits should cover five aspects including machinery, lockout procedures, alternative methods, training, and worker perception. Additionally, audits should provide answers to the following questions: (i) What are the sources of hazardous energy and the weaknesses or deficiencies in, for example, machine design, isolation device location, plant layout, and environmental factors? (ii) Are lockout procedures up-to-date, accessible and available, effective in controlling energy? (iii) Are alternative methods to padlocking up to date, accessible and available, effective in controlling energy? (iv) How is training carried out, is it effective, does it meet the expectations and problems of employees, is it consistent with changes in the company? (v) How do workers find lockout procedures: too elaborate, adequate, inefficient, cumbersome, unnecessary, unrealistic? (Grund, 1995).

Bahr (2018) mentioned that the frequency of audits and inspections varies from one industry to another, depending on the maturity of the industry, the complexity of the technology and the level of environmental risk. Audits can be planned or unplanned. Unplanned audits have the advantage of being transparent and realistic. The purpose of the audit must be defined prior to conducting. The audit should be based on the review of documents (e.g. lockout placards /procedures, accident report), targeted interviews, and observation of operations during the visit (Bahr, 2018). Kelley (2001) indicated that periodic audits and inspections of the application of lockout procedures are conducted to correct observed deficiencies. The auditor must observe a sufficient number of authorized employees who apply a lockout procedure and discuss with all other authorized employees. These observations can be planned or random. The author mentioned that audit results and outputs can be used in order to correct the deficiencies and to retrain authorized employees (Kelley, 2001). A study by Poisson and Chinniah (2016) showed the absence of an audit of lockout programs and procedures in most sawmills in the province of Quebec. Furthermore, the authors found no audit tools for application of lockout, and results of audits were not documented.

2.7.2 Audit tools for lockout

To conduct effective audits using valid and reliable audit tools is essential. Valid and reliable audit tools need to be tested for validity and reliability (Bigelow & Robson, 2005; Esposito, 2009; Huang & Brubaker, 2006). Robson and Bigelow (2010) showed that audit tools must be valid and reliable to help safety practitioners make proper decisions. The literature in the field of validity and reliability tests is rich and comprises different tests of reliability (e.g. inter-rater reliability and test-retest reliability) and validity (e.g. content validity and contrast validity) (Esposito, 2009; Fornell & Larcker, 1981; Hair et al., 2013; Huang & Brubaker, 2006; Landis & Koch, 1977; Lohr, 2002). In terms of reliability, a test for inter-rater reliability is prevalent and important. Inter-rater reliability is the degree of consistency of judgments made by different auditors (raters). To estimate the inter-rater reliability, statistical methods (e.g. using kappa or weighted kappa) are used for expressing the correlation among measurements made by auditors (Cronbach, 1951; Gouttebarge et al., 2004). Additionally, in terms of validity, tests for content validity and construct validity of a tool are important. Construct validity (e.g. criterion-related validity) is a test to understand the extent to which relationships exist between audit tool measures (e.g. audit score) and measures of other constructs (e.g. other measures of a safety program) based on audit expectations (Barrett et al., 1981; Hair et al., 2013). On the other hand, content validity indicates the comprehensiveness of the audit tool in its representation of system program concepts (Pannone, 1984; Terwee et al., 2007). Content validity is usually established through a panel of expert to assess the comprehensives of a tool, and to find whether the tool items pertaining to the topic are appropriate, understandable, and complete. In this regards, studies recommended calculating the content validity index (CVI) for the tool and each item (i.e. S-CVI and I-CVI respectively) since a high CVI index indicates high content validity (Lindell & Brandt, 1999; Lynn, 1986; Polit & Beck, 2006; Waltz et al., 2005).

Esposito (2009), Grund (1995), and Reese (2011) indicated that questionnaires and checklists can be used as audit tools to define expectations for evaluating safety measures (e.g. lockout). Daoust (2003) explained that audit tools should consist of a series of questions on: (i) identification of isolation devices; (ii) lockout equipment; (iii) lockout placards (i.e. the verification of de-energizing and the return to service); (iv) training; (v) modification of equipment (vi) the continuity of the lockout. Auditors can be supervisors or workers who are familiar with the equipment.

Burlet-Vienney et al. (2009) developed an audit tool for the general lockout program in order to help organizations review their lockout program. The tool presented by Burlet-Vienney et al. (2009) consisted of checklists for the elements of the general lockout program. Likewise, some of those elements were presented in Johnson (1996)'s study on the effectiveness of a lockout program. A self-audit tool (checklist) for lockout in manufacturing workplaces was introduced by Yamin et al. (2017). Although the tool showed good inter-rater reliability, the content of the tool was not complete and did not encompass all of the requirements and expectations of the application of lockout procedures carried out by authorized employees. For example, it is comprised of only fourteen questions to cover all the content on general procedures as well as the annual evaluation of lockout procedures and the availability of lockout hardware. In addition to the lack of questions (e.g. questions on continuity of lockout and external services), an assessment of some steps in a general lockout procedure was not included in the tool. Moreover, no examples were provided for the questions to help auditors assess the actual practice of lockout accurately and to reduce subjectivity. Their tool also consisted of six questions to assess a lockout program, but only the assessment of a training program for affected and authorized employees (Yamin et al., 2017).

2.8 Facilitating factors in the control of hazardous energies

In addition to the factors mentioned earlier, studies identified the other factors in facilitating the application of lockout, including (i) accessibility of isolation devices and lockout hardware; (ii) employee participation; (iii) accountability and disciplinary actions; and (iv) communication and awareness.

2.8.1 Accessibility of isolation devices and lockout hardware

Poisson and Chinniah (2016) recommended that lockout hardware should be easily available and located close to the machinery, and also isolating devices should be accessible with little effort required to switch them off. Similarly, Ross (2008) and Kelley (2001) mentioned that equipment such as valves, disconnectors, and other isolation devices must be easily accessible.

2.8.2 Employee participation

The successful implementation of safety programs to reduce the number of accidents will need management participation, and also cooperation between supervisors and workers through safety committees (Geldart et al., 2010; Ndana, 2018). The importance of safety committees in improving lockout/tagout procedures and programs was shown in the study by Parker et al. (2015a). Illankoon et al. (2019) stated that for lockout/tagout effectiveness, workers should be involved in the risk assessment process to evaluate risks of cognitive nature and physical risks.

Chinniah and Burlet-Vienney (2013) and Poisson and Chinniah (2016) recommended workers participating and feedback in (i) the development and improvement of lockout procedures, (ii) training program, and (iii) audit process.

2.8.3 Accountability and disciplinary actions

Hale and Borys (2013) stated that strict disciplinary rules and incentives had an impact on the application of safety procedures in organizations with the development of safety culture. The authors also showed that the tendency to transgress safety instructions can be reduced by means of increasing knowledge of workers. Chinniah and Burlet-Vienney (2013) and Poisson and Chinniah (2016) showed that companies did not tolerated violations of lockout procedures and progressive disciplinary steps would taken if employees violated the rules. Enforcement, accountability, and disciplinary measures are important factors in the effectiveness of the lockout application (Johnson, 1996; Kelley, 2001).

2.8.4 Communication and awareness

Communication and transfer information among employees during implementing lockout or alternative methods are vital. In that regard, the Canadian standard CSA Z460 (2013) and Quebec regulation ROHS (2017) require that the means of communications between host employees and outside services/subcontractors must be determined to keep each other informed of any activities or conditions that could adversely affect the application of hazardous energy control or the normal operation of machines, equipment, or processes. Nunes (2012) showed serious accidents during outsourced activities can be prevented through effective communication between employer and sub-contractors as well as long-term cooperation and knowledge sharing.

To increase awareness of employees (affected employees) from preventing the exposure to danger zones, warning and altering techniques can be helpful. Laughery (2006) mentioned that warning signs, and pictorial labels are clear and easy to understand for target audiences. Hapsari et al. (2018) showed that putting lockout/tagout signs around the work area was one of the important factors in knowledge transfer among mechanics in the mining industry.

2.9 Literature gaps

In the previous sections, the most relevant literature on the control of hazardous energies was discussed. The review of the literature showed that the requirements for controlling hazardous energies (specifically lockout) have been clarified in the last decade through the revisions of standards and regulations. However, alternative methods need to be elucidated in regulations (e.g. ROHS, 2017). The main causes of serious injuries and fatalities linked to the control of hazardous energies were investigated through the analysis of accident reports. It showed that organizations still have difficulty in implementing lockout and alternative methods, as evidenced by serous and fatal accidents. The absence of lockout and lack of lockout procedures were reported in many cases.

Despite this fact, the actual practice of lockout/alternative methods to control hazardous energies has been rarely investigated. For example, a study on the application of lockout has been conducted (Poisson & Chinniah, 2016), but it was limited to this specific industrial sector (i.e. sawmills). Likewise, Parker et al.'s studies (Parker et al., 2015a, 2015b) were limited to small metal fabrication businesses. In general, organizations in other sectors have different types of machinery, use alternatives to lockout based mostly on safety devices, and have external personnel intervening frequently. Thus literature gaps are identified in (i) the application of alternative methods; (ii) implementation of lockout by external services/ sub-contractors; (iii) performing the elements in the lockout program; and (iv) actual practices of hazardous energy control in organizations.

Moreover, although the lack of audits of lockout has been frequently reported, studies on the development of a self-audit audit tool are sparse. There are no proposed audit tools in the standards or regulations. The only tool proposed by Yamin et al. (2017) is incomplete and does not cover all the requirements of the North American standards and regulations. Therefore, there is plenty of room for improvement in developing a valid and comprehensive audit tool for lockout. The next chapter presents a framework to address these gaps.

CHAPTER 3 RESEARCH DESIGN AND PROCESS

This chapter explains the research design that outlines how the research methodologies are conducted to attain the research objectives. The structure of the thesis is determined by presenting the three dissertation articles.

3.1 Problem Statement and Research Objectives

The review of the literature indicated that accidents still occur in Quebec and the rest of the world due to the absence of lockout or inadequate lockout procedures. It shows that the control of hazardous energies is the challenge facing organizations. The previous chapter showed that there still exists a wide gap in the literature for demonstrating the state of the art, problems and shortcomings of the application of lockout and alternative methods within organizations that are diverse in terms of industry, size, and machinery/equipment. Moreover, the lack of audits for the application of lockout was reported. Thus, to address these gaps, this research focuses on exploring and evaluating the control of hazardous energies (i.e. lockout and alternative methods) on machinery, as well as developing a valid audit tool for monitoring the application of lockout. Therefore, the main objectives of this research are:

- To evaluate and analyze the implementation of lockout and alternative methods in order to comprehend the extent to which they are in accordance with relevant standards and regulations;
- To design and develop a self-audit tool for the application of lockout procedures on machinery.

3.2 Research Approach and Methods

The approach taken in this research is based on literature review and employing qualitative research methodologies (Miles and Huberman, 1994; Palinkas et al. 2015; Bricki and Green, 2007). The research approach is comprised of: (i) study on the control of hazardous energy on machinery using lockout and alternative methods; (ii) design of a self-audit tool for the application of lockout on machinery to control of hazardous energy.

3.2.1 Study on the control of hazardous energy on machinery using lockout and alternative methods

In order to achieve the first research objective, the application of lockout and alternative methods was studied in 14 organizations in Quebec, through qualitative research methodologies (i.e. a group interview, document review and site observation in each organization) that are presented in following paragraphs. The results of this study are presented in Chapter 4 and 5 (Article 1 and 2).

- Karimi, B., Chinniah, Y., Burlet-Vienney, D., & Aucourt, B. (2018). Qualitative study on the control of hazardous energy on machinery using lockout and alternative methods. *Safety science*, *107*, 22-34.
- Karimi, B., Burlet-Vienney, D., Chinniah, Y., & Aucourt, B. (2019). Hazardous Energy Control on machinery: Understanding the use of alternative methods to lockout. *Safety science*, *118*, 519-529.

3.2.1.1 Organization selection

For this part of the research, 14 organizations in the province of Quebec (Canada) were selected and recruited based on convenience sampling (Bricki & Green, 2007; Patton, 2002). The last organization selected was participated in the study after submitting the first article, and thus the results of the first study (Chapter 4) were based on the data from 13 organizations recruited, and the results of the second study were based on the data from the 14 organizations recruited. However, the data from the last organization did not add new findings to the study, and indeed the data was repetitive in all aspects of the first study.

The number of organizations (14) was a compromise involving the recruiting challenges (e.g. resources available) and the need to explore a range of work situations. Thus convenience sampling was selected as the sampling strategy for this qualitative research. The convenience sampling strategy is not a purposive strategy and researchers usually use it to save money, time and effort through collecting information from maximum participants who are accessible (Bricki & Green, 2007; Miles & Huberman, 1994; Palinkas et al., 2015). The organizations studied that were diverse in terms of industry, size, and number/type of machinery/equipment. The organizations selected were from the following sectors: metal fabrication, pulp and paper, printing, manufacturing of plastic products, food and agriculture industry, chemical industry, and health sector. The criteria for selection were used: (i) have a lockout program for at least five years; and (ii) previous experience in the application of lockout on machinery.

3.2.1.2 Development of a data collection tool

A questionnaire as a tool for collecting data through qualitative research methodologies such as interviews, and integrating data from site observations and document review was developed. The questionnaire consisted of more than a hundred questions (Appendix A) on the lockout program, application of lockout procedures, alternative methods, sub-contractor management, training, and audit/inspection. It was developed based on the requirements of the latest version of the regulation in force in Quebec (ROHS, 2017), the Canadian standard (CSA Z460, 2013) and on review of the literature. The questionnaire was tested on the first visit to ensure that the questions were clear and understandable. A consent form was sent to the organizations selected. Each visit lasted 3 to 4 hours and consisted of a group interview (due to time limit, the group interview was carried out) by asking the questions set out in the questionnaire and short observation of lockout hardware or other methods of control of hazardous energies. As far as possible, the group interview involved a technician/operator and a person in an occupational health and safety (OHS) role (for example, a safety supervisor). In each organization, the group interview was conducted by two skilled researchers who completed the questionnaire independently (but concurrently) based on participants' answers. They subsequently discussed and shared the results, and used observation data and documentation collected (e.g. written lockout program, lockout placards, audit tools and results, training documents) from each organization to verify the answers and to finalize the questionnaire.

3.2.1.3 Data analysis

After each visit, the questionnaire was completed and finalized (by the research team) through a combination of the interview notes, observation data and the documentation collected from the organizations. To facilitate qualitative analysis, spreadsheet programs such as Microsoft Excel© can be used for content analysis (Meyer and Avery, 2009). Therefore, the data from each organization were categorized in a Microsoft Excel© file. Each tab corresponds to the main items of the questionnaire and includes a number of columns based on the sub-items of the questionnaire and also 14 rows assigned to the organizations visited. All the answers of each interview were entered in the related cells. By using this method, the challenges in the organizations related to each item of the questionnaire were revealed. Finally, recommendations and possible improvements were proposed based on the shortcomings and problems observed.

3.2.2 Development of a self-audit tool for the application of lockout on machinery

To attain the second research objective, a self-audit tool for the application of lockout procedures on machinery was developed and tested for content validity. The results of this study are presented in Chapter 6 (Article 3). The design and validation methodologies are presented in the following paragraphs.

- Karimi, B., Burlet-Vienney, D., Chinniah, Y., & Aucourt, B. (2019). Design of a Self-Audit Tool for the Application of Lockout on Machinery in the Province of Quebec to Control Hazardous Energies. *Safety*, *5(3)*, 53.

3.2.2.1 Design of the self-audit tool

A safety audit can be based on regulatory or other compliance assessments (i.e. compliance-type audits) (Esposito, 2009). Occupational Safety and Health Administration (OSHA) recommends regular workplace inspection and compliance audits and mentions self-assessment auditing as an effective method to evaluate and improve safety programs (OSHA, 1999). In spite of this fact, conducting internal audits is less widespread in small companies (Grant & Brown, 2005; Parker et al., 2015b). Moreover, checklists and questionnaires are prevalent tools/methods for auditing safety management systems (Kuusisto, 2000). Checklists are helpful to conduct observational audits (Gray et al., 2016) based on the objectives of the audits of an OHS management system (Blewett & O'Keeffe, 2011). In this study, checklist statements were preferred to questionnaires, to reduce the subjectivity of assessment and to be easy to use for organizations (internal auditors). Thus, a self-audit tool was developed based on the questionnaire developed for the study (mentioned in section 3.2.1.2) and the results found in the study on the application of lockout and alternative methods (Article 1 and 2) as well as the relevant standards (i.e. CSA Z460, 2013 and ANSI/ASSE Z244.1, 2016) and the Quebec regulation (ROHS, 2017). Indeed, the developed tool must be (i) able to meet regulatory requirements; (ii) compressive (by contrast with existing tools); and practical (i.e. can be used for the actual lockout practices). On the other hand, according to the literature, lockout is applied by authorized employees through lockout procedures. Therefore, before the observation of the application of lockout, which is carried out by authorized employees, it is necessary to verify the availability and content of lockout procedures, the availability and condition of lockout materials/hardware, and the training records of authorized employees (using audit records can be useful as well). This verification is important for finding gaps or deficiencies and for correcting them before the evaluation of the application of lockout. Therefore, the self-audit tool for the application of lockout, which is presented in Chapter 6, is consisted of the two stages, (i) the pre-audit and (ii) the audit. These two stages of the tool comprised a set of checklist statements that were, in fact, the pre-requirements and requirements of the application of lockout procedures. The pre-audit (stage) of the application of lockout is comprised of four sections: (i) general conditions; (ii) content of the lockout procedure; (iii) authorized employee/ sub-contractor; and (iv) required lockout hardware/material. For each statement, if the pre-requirement or requirements were met, they could be marked with a check (✔); if not, they could be marked with an x (X), and if not applicable, they could be marked (N/A). The latter was clarified in related checklist statements. In the pre-audit stage, if each checklist statement was not met, the required actions would need to be taken by auditors or organizations. In this regard, the required actions were defined and embedded in the pre-audit stage (on the tool) to help organizations address problems. In addition, the audit (stage) of the application of lockout consists of two sections: (i) de-energizing steps; and (ii) re-energizing step. In the audit stage, during the observation of the application of lockout, auditors could write their comments in the designated column of the tool. The tool also consisted of general instructions and general information.

3.2.2.2 Content validity of the self-audit tool

The self-audit tool was evaluated for content validity through a two-step process, including review by a panel of experts and testing by the six recruited organizations in the province of Quebec. The expert panel in this study comprised six experts in the control of hazardous energy who were the representatives of different sectors including: (i) governmental sector on standard and regulation (i.e. CNESST); (ii) equipment and machinery fabrication; (iii) pulp and printing industry; (iv) transport and warehousing; (v) hospital sector; and (vi) manufacturing sector. In the first step, the experts were asked to judge the appropriateness and relevancy of the checklist statements (i.e. items) of the tool and the extent to which they agree with them (a scale ranging from irrelevant to highly relevant). Afterward, all feedback was collected and then the content validity index (CVI) was assessed through (i) calculation of the content validity index for items [I-CVI] (Lynn, 1986); and (ii) calculation of the content validity index for scale [S-CVI] (Waltz et al., 2005) as shown in Appendix C. Polit and Beck (2006) proposed that both I-CVI and S-CVI be calculated for the scale being judged to test content validity. The authors recommended that a valid scale requires a minimum I-CVI of .78 (for 6-10 experts as explained by Lynn, 1986) for each item and a minimum average S-CVI of .90 for the scale/tool. Lynn (1986) demonstrated the proportion of experts required to perform content validity beyond the 0.05 level of significance. The author showed that I-CVI of 1.00 with three to five experts and a minimum I-CVI of .78 for six to 10 experts is necessary to achieve a high level of accuracy in identifying items. The authors also showed that a minimum of three experts is necessary, but more than 10 was probably unnecessary. Polit and Beck (2006) recommended two rounds of expert review if the initial I-CVIs need substantial improvements.

In the next step, the self-audit tool was tested by six organizations in order to receive their feedback (more practical points of view) after using this tool in terms of the content, applicability (i.e. easiness to use), and completeness of the tool. This step was the assessment of content validity of the tool, which had been assessed by the panel of experts in the previous step, in real situations where the tool was used for the actual lockout practices by the organizations selected. These six organizations (in the province of Quebec) were selected and recruited on the basis of convenience sampling (Bricki & Green, 2007; Patton, 2002) as mentioned in section 3.2.1.1. The organizations were diverse in terms of industry, size, and machinery/equipment (as a heterogeneous group of organizations) and had at least five years of experience with lockout on machinery that was the main selection criterion. Moreover, the short and simple questionnaire (which is presented in Chapter 6) was provided along with the self-audit tool to help organizations easily provide their feedback about the content validity of the tool (i.e. clarity, completeness, and usability/applicability). However, specific methods with regards to other tests (e.g. usability measurement or criterion-related validity) were not carried out. For example, the organizations were asked to provide their feedback about the usability of the self-audit tool through only three questions.

CHAPTER 4 ARTICLE 1: QUALITATIVE STUDY ON THE CONTROL OF HAZARDOUS ENERGY ON MACHINERY USING LOCKOUT AND ALTERNATIVE METHODS

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This article was published in Safety Science 107 (2018): 22-34.

Abstract: In Canada, like many countries, the national standard and provincial regulations require that workers performing maintenance, repair, and un-jamming activities on machinery must follow lockout procedures. However, the high number of accidents linked to hazardous energies and machinery shows that organizations have difficulty with the application of lockout arrangements or use of alternative methods. Therefore, it is important to understand how organizations implement lockout programs and procedures, and the extent to which they are in accordance with relevant standards and regulations. In this qualitative research, the application of lockout and alternative methods was studied in 13 organizations in Quebec, through a group interview, document review and site observation in each organization. In each organiztion, the researchers conducted a group interview and completed a questionnaire, which included more than a hundred questions on the lockout program, application of lockout procedures, alternative methods, sub-contractor management, training, and audit/inspection. The researchers then used observation data and documentation collected from each organization to verify interviewee responses and to finalize the questionnaire. The shortcomings found included: (i) incomplete lockout programs; (ii) missing steps in general lockout procedures; (iii) not reading the placards; (iv) using alternative methods without risk assessment; (v) poor training for alternative methods; (vi) absence of supervision and coordination of subcontractors; (vii) and lack of audit tools and documentation of audit results. Despite the shortcomings, actual lockout practices in the organizations visited were better than what was described in their lockout programs. Recommendations for addressing identified shortcomings are proposed.

Keywords: Safety of machinery, Lockout, Equipment, Regulation, Alternative methods

4.1 Introduction

Workers intervene in all phases of a machine life cycle (i.e. installation, operation, maintenance, troubleshooting, repairs, adjustments, set-up, production disruptions, cleaning, and dismantling) and consequently their exposure to different types of machinery hazards and hazardous energies can result in injury or death (Chinniah, 2015; Yamin et al., 2016). Various types of machinery hazards are listed in standards such as International Organization for Standardization [ISO] (ISO 12100, 2010), Canadian Standards Association [CSA] (CSA Z460, 2013), American National Standards Institute [ANSI] (ANSI B11-TR3, 2000), and in the scientific literature (e.g. Chinniah et al. (2007) and Bluff (2014)).

Regulations such as Occupational Safety and Health Administration [OSHA] (OSHA 29 CFR 1910.147, 1989) in the U.S., and Quebec's Regulation Respecting Occupational Health and Safety (ROHS, 2017) address the minimum requirements necessary for the methods which are applied during the non-production phase (i.e. service, repair, and maintenance) of machinery and equipment to control hazardous energies (e.g. electrical, hydraulic, pneumatic, kinetic, potential, chemical, and thermal in nature).In addition to regulations, the international standard ISO 14118 (2017) and North American standards such as CSA Z460 (2013) in Canada and ANSI/ASSE Z244.1 (2016) in the US describe the requirements for, and provide guidance on, the control of hazardous energies which is also referred to as lockout/tagout. These standards also advise on alternative methods to lockout.

In Quebec, regulations on lockout were strengthened in 2016 as shown in

Table 4-1. Obligations are now in line with North American standards and OSHA 29 CFR 1910.147 (1989). Previously, lockout was mentioned in the regulation without any explanation of what to do. However, in Canada, CSA Z460 was published in 2005 and the control of hazardous energy has been in practice in some organizations in Quebec for some time.

Table 4-1 The most important updates in Quebec's regulation in terms of the control of hazardous energies (ROHS, 2017)

Regulatory changes (Article 188.1-13: 2017)	Content
1	Develop a lockout procedure (lockout placard) for each machine or equipment
2	Identify the machine, the energy sources, the lockout material and the steps required to control the energy
3	Train workers on lockout and verify their competencies
4	Manage subcontractors, i.e. the employer's responsibility for supervising the work assigned to another employer or a self-employed worker
5	Describe the type of lock to be used
6	Use of a specific procedure in case a lock is forgotten on a machine or a key is lost
7	Use of alternative methods through a risk assessment when lockout cannot be applied

4.1.1 Lockout program and procedure

A lockout program is the document that establishes the company's general policies and procedures for implementing lockout. It also provides the instruction for regulatory compliance. Lockout programs should contain the following elements: (i) identification of the hazardous energy covered by the program, (ii) identification of the types of energy isolating devices, (iii) identification of the types of de-energizing devices, (iv) selection and providing of protective materials and hardware, (v) assignment of roles and responsibilities, (vi) determination of shutdown, de-energization, energization and start-up sequences; (vii) examples of written lockout procedures for machines, equipment, and processes, (viii) training of employees, and (ix) auditing of program elements (Burlet-Vienney et al., 2009; Chinniah, 2010; ANSI/ASSE Z244.1, 2016; CSA Z460, 2013; Poisson & Chinniah, 2015).

The lockout procedure provides a step-by-step approach that the authorized employee (one who is trained on lockout) must follow in order to prevent injury from the unexpected (inadvertent) start-up, energization or release of stored energy. The general lockout procedure requires: (i) preparation for shutdown, (ii) machine, equipment or process shutdown, (iii) machine, equipment or process isolation, (iv) application of lockout devices, (v) dissipating and controlling stored energy (de-energization), (vi) verification of isolation (start-up test or using measuring instruments) (Chinniah & Burlet-Vienney, 2013; CSA Z460, 2013; Poisson & Chinniah, 2016; ROHS, 2017). The lockout procedure (and return to service) for a machine, equipment or process needs to be readily accessible to authorized employees and described in a placard with all necessary information.

4.1.2 Alternative methods to lockout

According to OSHA 29 CFR 1910.147 (1989) and CSA Z460 (2013), traditional lockout to a full zero energy state is not practicable in all situations. When lockout affects the tasks that are integral to the production process by design, or traditional lockout prohibits the completion of specific tasks, other hazardous energy control methods can be used. According to the Canadian standard, the tasks considered integral to production exhibit most of the following characteristics: (i) of short duration, (ii) relatively minor in nature, (iii) occurring frequently during the shift or production day, (iv) usually performed by operators, set-up persons, and maintenance personnel, (v) represent predetermined cyclical activities, (vi) minimally interrupt the operation of the production process, (vii) exist even when optimal operating levels are achieved, and (viii) require task-specific personnel training (CSA Z460, 2013).

Before adopting other methods of control, the user should conduct a risk assessment that demonstrates the effectiveness of the protective measures. The standards such as ISO 12100 (2010), CSA Z460 (2013) and ANSI/ASSE Z244.1 (2016) provide guidance on conducting risk assessments and list alternative methods.

4.1.3 Accidents related to the absence of, or improper lockout program and procedures

In spite of various lockout-related standards and regulations, accidents caused by the absence of lockout or inadequate lockout procedures still happen. In the U.S., OSHA inspectors' reports show that companies were given citations for the improper lockout because of (i) lack of training and communication in lockout procedures, (ii) absence of lockout procedures and (iii) lack of audit and periodic inspections of lockout procedures (OSHA, 2015).

Recent studies analyzing accidents involving machines during the non-production phase such as in US (Bulzacchelli et al., 2008; Martin & Black, 2015; Ruff et al., 2011), Canada (Chinniah, 2015), UK (Shaw, 2010), France (Blaise & Welitz, 2010), and Netherlands (Aneziris et al., 2013) reveal that the absence of or deficient lockout procedures is one of the main causes of serious and fatal accidents.

The US Bureau of Labor Statistics (BLS, 2016) revealed that in 2015, a total of 722 fatal work injuries (15%) occurred as a result of contact with objects and equipment. Moreover, OSHA reported that lockout was the fifth most cited OSHA violation in 2015 and 2016. In those two years, OSHA issued respectively 3,585 and 3,308 citations for alleged violations of the lockout/tagout standard (OSHA, 2016; OSHA, 2015).

In Canada, in 2013, 17 % of orders issued by the Ontario Ministry of Labor to employers were because of lockout and machine guarding violations (Ontario Ministry of Labor, 2016). Moreover, in 2015, Quebec's workers' compensation board reported that on average, 10% of fatalities in that province occurred annually due to poor or absent lockout procedures (CNESST, 2016).

4.1.4 Gaps and shortcomings associated with lockout/tagout reported in the literature

Chinniah (2015) identified the main cause of fatal and serious injuries involving fixed machinery from 106 accident reports in Quebec. This study reported that 54 accidents (51%) were linked to the absence of or poor lockout. In fact, lockout procedures were not used during maintenance, repairs and unjamming activities. The study found that having a lockout program does not imply that lockout procedures are being applied.

In another study, 457 incident reports from six multinational organizations in different industries were analyzed (Martin & Black, 2015) and was found incidents with the potential to cause serious injuries and fatalities were strongly linked to deficiencies in management systems related to lifesaving policies, programs (e.g. lockout, machine guarding and barricades, etc.) and risk assessment. The study indicated that a serious injury or fatality happens during routine operation/production or maintenance/repair tasks when these management systems are either absent, ineffective, or not complied with.

Poisson and Chinniah (2015, 2016) showed the difficulties and gaps of the actual lockout practices in eight sawmills in Quebec. They analyzed the application of 57 lockout procedures and of seven programs. The studies identified shortcomings such as: (i) incomplete hazard identification, (ii) outdated lockout program and procedures, (iii) applying padlocks to control systems during minor unjamming on machinery against lockout principles, (iv) issuing permits as alternatives to lockout for troubleshooting on machinery without any risk assessment, (v) lack of audits on lockout, (vi) not performing the verification step and (vii) not reading the placards during lockout. Finally, Parker et al. (2016) in the U.S. demonstrated that only 8% of the 160 small firms audited complied with lockout procedures at the beginning of the study.

4.1.5 Facilitating factors on the application of lockout

Several studies identified the main factors in facilitating the application of lockout. The studies by Poisson and Chinniah (2015, 2016) revealed that the main factors facilitating the application of lockout to machinery in sawmills were: (i) visible management leadership on lockout, (ii) workers being empowered to follow the majority of steps in the lockout procedures, (iii) lockout hardware being available and located close to the machinery, (iv) isolating devices being accessible with little effort required to switch them off, (v) procedures being simple to apply, resulting in little time spent on them and reducing the incentive to bypass them, (vi) feedback from workers improving the lockout procedures, (vii) workers participating in the development of procedures, fostering a sense of ownership, (viii) providing adequate training on lockout procedures, (ix) enforcement of lockout procedures and accountability, (x) violations to lockout procedures are not tolerated and progressive disciplinary steps are taken, (xi) training program, integrating feedback and setting goals, (xii) adding a task risk-analysis system, (xiii) revising minor and major unjamming operations, (xiv) and having a well-designed audit process as a feedback method for the application of lockout procedures.

4.2 Originality and Objective

Based on the literature review, few studies exist on the actual application of lockout. For example, the application of lockout has been studied in sawmills, but the study was limited to this specific industrial sector. However, compared to sawmills, organizations in other sectors have different types of machinery, use alternatives to lockout based mostly on safety devices (i.e. technical means as compared to work permits) and have external personnel intervening frequently.

The main objective of the present research is to study the application of lockout for the first time, in a variety of enterprises and organizations and industries. In that regard, it is important to understand how lockout is implemented and to compare their current practices with standard and regulatory requirements (CSA Z460, 2013; ROHS, 2017). Furthermore, gaps and shortcomings will be identified, and recommendations to improve practices will be proposed. The 13 organizations in Quebec, which have been visited, constitute a heterogeneous sample. In qualitative research, diversity is a valuable strategy. Moreover, the provincial regulation and the Canadian standard on lockout apply to a wide range of organizations and this study aims at understanding how such organizations apply lockout and its alternative.

4.3 METHODS

4.3.1 Organization selection and recruitment

13 organizations in the province of Quebec (Canada) were recruited in 2017 for the study. The number of organizations (13) was a compromise involving the recruiting challenges (e.g. resources available) and the need to explore a range of work situations. However, the latter was covered by recruiting organizations that were diverse in terms of industry, size, and machinery/equipment used as set out in Table 4-2. Thus convenience sampling was selected as the sampling strategy for this qualitative research. The convenience sampling strategy is not a purposive strategy and researchers usually use it to save money, time and effort through collecting information from maximum participants who are accessible (Bricki & Green, 2007; Miles & Huberman, 1994; Palinkas et al., 2015). In convenience sampling, collecting the most data from a limited number of cases is the first priority (Bricki & Green, 2007; Palinkas et al.,

2015; Patton, 2005). In terms of credibility, the quality of data collected is increased by using trained interviewers and an appropriate interview schedule (Bricki & Green, 2007; Patton, 2005).

The organizations selected were from the following sectors: metal fabrication, pulp and paper, printing, manufacturing of plastic products, food and agriculture industry, chemical industry, and health sector as explained in Table 4-2. Moreover, the following criteria were used:

1. The organization must have a lockout program for at least five years and apply lockout procedures on machinery.

2. Ideally, the organization should resort to subcontracting, use alternatives to lockout, and have already conducted an audit of its lockout program and its application.

3. Organizations with no previous experience in the application of lockout are excluded from the study.

Table 4-2 General information of thirteen organizations in the study

Enterprise	**Sector**	**Size (Number of employees: <100; <500; ≥500)**	**Safety committee**	**Number of items of machinery/equipment (approximately)**
A	Chemical industry	<100	Yes	125
B	Chemical industry	<100	No	50
C	Food industry	<500	Yes	1000
D	Pulp and Paper	<500	Yes	4000
E	Plastic industry	<500	Yes	200
F	Food industry	<500	Yes	500
G	Plastic industry	<100	Yes	100
H	Fabrication	<500	Yes	800
I	Recycling	<100	Yes	6

Table 4-2 General information of thirteen organizations in the study (cont.)

J	Printing	<500	Yes	100
K	Horticulture and agriculture	<500	Yes	50
L	Aerospace	>500	Yes	1300
M	Health service	>500	Yes	450

4.3.2 Developing a questionnaire as a major data collection tool

The research team developed, validated and used a questionnaire as a tool for collecting data through interviews, and integrating data from site observations and document review. The questionnaire was developed based on previous studies on the content of lockout programs as well as the application of lockout in sawmills (Chinniah, 2010; Chinniah & Burlet-Vienney, 2013; Poisson & Chinniah, 2015). The questionnaire contained the requirements of the latest version of the regulation in force in Quebec (ROHS, 2017) and the Canadian standard (CSA Z460, 2013). Six items were studied, namely: (i) the general lockout program, (ii) application of lockout, (iii) other methods of control of hazardous energies, (iv) sub-contractor management, (v) training and (vi) audit /inspections. The sub-items and questions were defined for each item. Table 4-3 presents the items, sub-items, and the number of questions for each in the questionnaire. The detailed questionnaire including most of the questions related to each item/sub-item is presented in Appendix A.

Table 4-3 Items and sub-items of the questionnaire on the application of lockout

Item	Sub-item	Number of Questions	Related articles of regulation or standard
General lockout program (policies)	Content and development of lockout programs	9	CSA Z460:13
	Utilization of the lockout program and regulation update	7	(ROHS, art. 188.1)
Application of lockout	Targeted equipment and machines, tasks and employees (affected and authorized)	11	(ROHS, art. 188.2)
	Development, content, and the application of lockout procedures and placards	15	(ROHS, art. 188.3, 188.5, 188.6, 188.7)
	Lockout hardware (e.g. lockout stations, energy-isolating devices, lockout devices) and utilization principles	10	(ROHS, art. 188.11)
	Management of specific cases (continuity of lockout, case of absence of authorized person or loss of keys)	8	(ROHS, art. 188.12)
Other methods of control of hazardous energies (alternatives to lockout)	Non-application of lockout procedures	3	
	Other methods (alternative methods) to lockout	14	(ROHS, art. 188.2, 188.4, 188.5, 189.1) CSA Z460, S.7.4.2
Sub-contractor (external services) management	Sub-contractor management (other employers or independent workers)	10	(ROHS, art. 188.9, 188.10) CSA Z460:13
Training and records	Training management and documentation	11	(ROHS, art. 188.8) CSA Z460:13
Audit/ inspections	Audit of the lockout program, lockout procedures, and application of lockout/ Periodical inspections	10	(ROHS, art. 188.5) CSA Z460:13

In terms of content validity, the questionnaire was tested on the first visit in order to ensure that the questions were clear and easy to understand. A consent form was sent to the organizations selected. The research team also asked for the documents (e.g. written lockout programs and lockout procedures, examples of lockout placards, audit tools and results of the audits, lockout training documents), which were collected at the time of the scheduled visit. Each visit lasted 3 to 4 hours and consisted of a group interview (asking the questions set out in the questionnaire) and short observation of lockout hardware or other methods of control of hazardous energies. When possible, photographs were taken for additional information or to illustrate specificities and actual practices.

As far as possible, the group interview involved a technician/operator and a person in an occupational health and safety (OHS) role (for example, a safety supervisor). In each organization, the group interview was conducted by two skilled researchers who completed the questionnaire independently (but concurrently) based on participants' answers. They subsequently discussed and shared the results, and used observation data and documentation collected from each organization to verify the answers and to finalize the questionnaire.

4.3.3 Data analysis

The study applied these qualitative methods in order to answer the following questions: How do the organizations apply lockout procedures? How do the actual practices of lockout compare with the theory and state of the art? To what extent is the application of lockout and other methods of control of hazardous energies (alternative methods) in compliance with the current Canadian standard and Quebec regulation? What are technical or organizational challenges and shortcomings in lockout arrangements?

The data from the 13 organizations were handled through the following steps:

1. After each visit, the questionnaire was completed and finalized by combining the interview notes from the two researchers, observation data and the documentation collected from the organizations.

2. The data from each organization were categorized by tabs in a Microsoft Excel© file in order to facilitate qualitative analysis (Meyer and Avery, 2009). Each tab corresponds to the items listed in Table 4-3. Each tab includes a number of columns based on the sub-items of the questionnaire and also 13 rows assigned to the organizations visited. All the answers of each interview were entered in the related cells.

3. The analysis revealed the challenges in the organizations related to each item of the questionnaire (Table 4-3). The analyses also highlighted how the organizations dealt with compliance with the current regulation (ROHS, 2017) and standard (CSA Z460, 2013) in the application of lockout and alternative methods.

4. Recommendations and possible improvements were proposed based on the shortcomings and problems observed.

4.4 Results and discussion

The findings for the six subsections of the questionnaire are described in this section; namely the general lockout program, application of lockout, alternative methods of control of hazardous energies, training, sub-contractor, management and audit/ inspection are described in this section. The state of the art, the gaps and problems observed, and finally, the recommendations are tabulated for each subsection. To provide an indication of the prevalence of particular responses, the number of organizations is presented as a proportion of the 13 organizations.

4.4.1 The general lockout program

The organizations' main objectives for lockout were zero energy (7/13), protection of workers (3/13), and job safety (2/13). Their lockout programs were drafted or revised between 2012 and 2016 by using the CSA Z460 (9/13), the old version of ROHS (8/13) and/or the current version of ROHS (4/13). One organization had no written lockout program.

The majority of organizations were aware of the regulatory changes introduced in January 2016 related to lockout (10/13) [(i.e. Quebec's ROHS)]. However, in eight organizations the regulatory changes had no impact on their lockout programs because they had revised them based on CSA Z460 (2013) and they had made no other changes or improvements to their lockout practices. On the other hand, four organizations reported that they had updated their lockout placards as a result of the current regulation, and thus had improved their lockout practices.

The content of the lockout programs varied. One organization had a one-page lockout program without enough explanation. Four organizations had programs which were less than 10 pages in length. Although 10/13 lockout programs included the main elements as set out in the questionnaire, several elements were missing or incomplete (Table 4-4). For example, the audit was mentioned in only 5/13 programs, but on the other hand the roles and responsibilities were explained in 11/13 programs (i.e. the role and responsibilities of the director (8/13), operation supervisors (10/13), lockout coordinator (9/13), and authorized personnel (11/13) were clearly elaborated in the lockout program). The content of programs will be discussed in the next subsections.

Table 4-4 Summary of elements found in general lockout programs

Subject	A	B	C	D	E	F	G	H	I	J	K	L	M
Written lockout program	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Roles and responsibilities	Yes	Yes	Yes	Yes	Yes	Yes	No		Yes	Yes	Yes	Yes	Yes
Lockout hardware and devices	Yes	Yes	Yes	Yes	Yes	Yes	No		Yes	Yes	Yes	Yes	Yes
Continuity of lockout	Yes	Yes	Yes	Yes	Yes	Yes	Yes		No	Yes	Yes	Yes	No
General lockout procedure	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Alternative methods for control of hazardous energies	Yes	No	No	Yes	Yes	Yes	No		No	Yes	No	No	No
Training	Yes	No	Yes	Yes	Yes	Yes	No		No	No	Yes	Yes	No
Subcontractor management	Yes	No	Yes	Yes	Yes	Yes	No		No	No	Yes	Yes	No
Audit/ Inspections	Yes	Yes	No	Yes	Yes	No	No		No	No	Yes	No	No

4.4.2 Application of Lockout

4.4.2.1 Non-application of lockout procedures

Almost all the organizations (12/13) reported that they had had no serious accidents linked to non-application of lockout procedures in recent years. Nevertheless, half of the organizations (6/13) had experienced near-miss incidents because of, for example, closing the wrong circuit breaker, unplugging the wrong cable or not carrying out a start-up test during work. This finding is consistent with Chinniah (2015) who found that accidents can occur in organizations that have lockout programs. An additional finding in the present study is that half the organizations (7/13) used disciplinary measures in the event of non-application of lockout procedures by employees. The measures ranged from verbal warnings, written warnings, unpaid leave and work contract termination. Hale and Borys (2013) have questioned whether disciplinary actions have an impact on the application of safety procedures. They showed that greater experience/knowledge/training of workers can reduce the tendency to transgress safety instructions. They also mentioned that strict disciplinary rules and incentives had an impact on several organizations with the development of safety culture. Raising employee's awareness of the advantages of lockout may improve the safety culture in organizations.

4.4.2.2 Target equipment, lockout devices and hardware

In this section, the lockout devices and hardware used in the 13 organizations are presented, as well as the target activities and equipment linked to lockout.

The Canadian standard CSA Z460 (2013) and Quebec's ROHS (2017) (Art.188.2) apply, but are not limited to, activities such as: erecting, installing, constructing, repairing, adjusting, inspecting, unjamming, setting up, troubleshooting, testing, cleaning, dismantling, servicing, refurbishing, and maintaining machines, equipment, or processes.

In most of the organizations studied, lockout was most applicable to maintenance, service, repair, and cleaning activities. In addition, electrical, pneumatic and hydraulic energies were the most common hazardous energies targeted in lockout arrangements in all the organizations. Hazardous energies were addressed in lockout programs of eight organizations.

The organizations applied lockout or alternative methods to most of their equipment and machinery were included in the application of lockout, but a few of the organizations excluded heating, ventilation and air cooling systems, and also the mobile equipment (e.g. forklift trucks) from the application of lockout or alternative methods.

In terms of equipment design characteristics, ISO 12100 (2010) advises that machines have to be equipped with the technical means to achieve isolation from power supplies and the dissipation of stored energy. These design factors were absent from all the lockout programs. However, in practice, participants in nine organizations stated that when purchasing new installations or modifications to equipment, they assumed them to be easily locked out but did not actually consider whether design features facilitated lockout.

In most of the organizations (10/13) participants stated that lockout devices were coded and easily accessible, while in two organizations participants advised that access to a few of the devices (e.g. valves) was difficult due to the height and the distance between them.

In all the organizations, lockout stations were available and fully equipped, including all the required lockout devices (e.g. personal locks and keys) and appropriate lockout accessories (e.g. hasps chains, valve covers, lockout boxes, and lockout jaws). Figure 4-1 shows a lockout station and the hardware used in one of the organizations.

In terms of hardware utilization principles, participants in all the organizations stated that authorized employees used a single key and their own personal padlocks remained in their possession. Double key padlocks were available in five organizations but, in practice, they did not utilize them and kept the double key in a locked box. In other cases, double keys were cut and discarded. In regard to padlock tagging (information labels) these were used in six organizations, and in others, padlocks were customized or registered.

All the organizations used individual and group lockout arrangements. In the case of group lockout, the box was locked or sealed by the operator. Other workers involved (e.g. subcontractors) put their padlock on the box after the operator. Two organizations used complex group lockout arrangements with more than one box.

For the use of non-personalized padlocks (e.g. borrowing padlocks, etc.), only half of the organizations (6/13) provided a register for lockout hardware, 2/13 organizations used label tags, and the others had no means of tracking the history of lockout work. Recommendations to address key shortcomings in this section are presented in Table 4-5.

Table 4-5 Shortcomings observed and possible improvements concerning target equipment, lockout devices and hardware

Standard and regulation on lockout	Lockout programs	Actual lockout practices	Recommendation or possible improvements
Energy-isolating devices: - Machines, equipment are designed to facilitate lockout (CSA Z460, clause 5.2.1)	- Not mentioned in the programs	- Not directly considered when purchasing equipment (9/13 organizations)	- Add in the program: Explain how to ensure that energy-isolating devices are capable of controlling and/or dissipating hazardous energy. Moreover, when purchasing equipment, ensure that its design features allow for the lockout (to facilitate the application of lockout)
- Energy-isolating devices are labeled/marked, capable of being locked and accessible (CSA Z460, clause 5.2.3)	- Not mentioned in 8/13 programs	- Problem with access to energy isolating devices (e.g. valves). The devices were not all coded even in the organizations which mentioned marking and labeling devices	- Code or mark all the energy-isolating devices. Provide facilities for workers who perform lockout to access isolating devices and to switch them off with little effort
Providing a register in case of using non-personalized padlocks (ROHS art. 188.11)	Not mentioned in the programs	Lack of a register in 5/13 organizations	Update and add the requirements in the program. Provide a register to record: (i) identification of each single keyed padlock, (ii) name of each person to whom a lock is given, (iii) name and telephone number of the employer of each worker who was given a lock (if applicable), (iv) date and time the padlock is given, (v) date and time the padlock is returned

Figure 4-1 Lockout station

4.4.2.3 Content and application of lockout procedures/placards

This section presents key elements related to the content and the application of lockout procedures in the organizations visited. Compliance with the Canadian standard and Quebec regulation in force is also analyzed.

Most of the organizations had lockout placards for their target equipment and machines (10/13). The contents of lockout the procedures/placards covered most of the requirements of the regulation and the standard. However, in three organizations, we observed that the lockout placards for some of the equipment were missing. For instance, in one organization some the valves had no placards, but there was a step-by-step guide to intervention in these valves including a checklist, proposed personal protective equipment (PPE), etc.

The organizations had lockout placards for equipment (6/13), tasks (2/13), and both tasks and equipment (5/13), which might be the reason for the difference between the number of items of equipment and placards (e.g. one organization had approximately 500 equipment/machines, but had 875 lockout placards). The organizations provided lockout placards next to or on equipment (8/13), electronically and on the internal network (4/13), or in the lockout station (1/13). Figure 4-2 shows an example of a placard posted on a machine. In the case of the electronic version of the placards, employees had to print them. This difficulty in accessing some of the placards might explain why reading them was compromised in these organizations. For example, 10/13 organizations reported that employees only sometimes read the placards in applying lockout. In addition, in these organizations, in the group lockout approach, only the principal authorized employee read placards. Not reading placards can be problematic, especially when the placards have been updated or workers have limited experience. Poisson and Chinniah (2015) found that lockout placards were not used when experienced workers were familiar with the machinery and when one or two energy sources were isolated. Consequently, switching off the wrong isolating device and not verifying that energy was isolated could occur. Not reading placards could also increase the risk of human error, especially when a worker is unaware of changes made to machinery and the lockout placard for it.

Figure 4-2 Lockout placard posted on a machine

Over half of the organizations (8/13) reported that they led and encouraged employees to utilize the lockout placards by requiring them to sign the placards or the register (6/13), or by filling out a work permit (2/13). Furthermore, the application of lockout procedures was recorded and documented for several years in nine organizations, through filling out the lockout placards or using the register.

Only 6/13 organizations provided pictures or pictograms in the lockout placards to facilitate understanding by workers. However, participants in the other organizations reported that employees had no problem with the application of lockout procedures.

Although, the validation of the lockout placards before use was addressed in only half the lockout programs, in practice most of the organizations performed validation to ensure that the lockout procedures were effective before using them. For example, the validation was performed by the supervisor, authorized operators or the OHS committee.

Most of the organizations reported that they had no problems with the verification step (i.e. verification of isolation) of the application of the general lockout or with the steps of the return to service procedure. Start-up test and pressure gauge checking were the most popular techniques for the verification step in over half of the organizations (7/13). Practices such as the systematic use of a lockout box or the presence of the supervisor for the start-up test are vital elements in the application of lockout. Besides, we found that the use of lockout boxes was widespread in five organizations because it allowed better control of the application of lockout. In these organizations, the use of a lockout box was a systematic element for the continuity of the lockout, the efficient application by authorized workers, the supervision of subcontractors and for audits.

The duration of the application of lockout procedures varied from a few minutes to one hour, and many hours in one organization. Another organization used the Single-Minute Exchange of Die (SMED) method to reduce the time required to apply the lockout procedure. Poisson and Chinniah (2015) found that one of the main factors favoring the application of lockout in sawmills was when procedures are simple to apply, resulting in less time spent on them and reducing the incentive to bypass them.

In summary, although most of the organizations prepared the lockout placards for their target equipment, machines and processes, there were some missing steps or elements in placards. In addition, reading placards during the application of lockout and also documentation of the application of lockout were compromised. Table 4-6 presents key shortcomings and recommendations for addressing them.

Table 4-6 Shortcomings observed and possible improvements concerning the content and application of lockout procedures

Standard and regulation on lockout	Lockout programs	Actual lockout practices	Recommendation or possible improvements
Validation of lockout placards before using (CSA Z460, clause 7.3.2.5.3)	Not mentioned in 6/13 programs	Missing in only one organization	Explain the process of test and validation of lockout placard before using in the workshop (especially for updating, new machines, and equipment), how and by whom in the programs
Lockout placards to be accessed, used, read (CSA Z460, clause 7.3.2.5.3; ROHS, art. 188.5)	Not mentioned in 2/13 programs	Reading the lockout placards was compromised in 10/13 organizations. Electronic versions of lockout placards were not easily accessible in 4/13 organizations	Encourage worker to read and follow the placards in terms of the safety culture. Post the placards near to equipment and make them easily and readily accessible. In case of multiple energy sources, require signing of the placard
Documentation of lockout placards (CSA Z460, clause 7.3.2.5.5)	Not mentioned in the programs	No records at 4/13 organizations	The date of creation, revision, and update of each lockout placard must be documented
Lockout procedure steps/elements: - Identification and location of every control device (ROHS, art. 188.6) - Warnings and special instructions (CSA Z460, clause 5.4; ROHS, art. 323)	- Not mentioned in the programs - Not mentioned in 8/13 programs	- The missing step in the placards - "Inform the staff involved in the work" was missing in 6/13 organizations	- Add the step in the general lockout procedure and in the placards if applicable - Add the step "mark off the areas where intervention is being performed" in the content of lockout procedures. This step can be important when organizations have a large number of equipment and employees

4.4.2.4 Management of special cases

In this section, the management of special cases (e.g. continuity of lockout during shift changes, forgotten/losing key) are evaluated and the results are presented.

According to the Canadian standard, lockout procedures shall provide for the continuity of lockout in the event of shift or personnel changes. All but one of the organizations (12/13) had an evening shift and the application of lockout was similar to the two shifts (i.e. the day and night shifts). The continuity of lockout was addressed in nearly all of the lockout programs (10/13). The methods used for ensuring continuity of lockout were: placing a departmental or supervisor padlock (9/13), placing a coded seal on the lockout box (1/13), or transferring information (1/13). In two organizations the padlocks were left behind from the evening until the day shift.

In other words, the coded seals and departmental padlocks were two popular ways to ensure continuity of lockout. According to the regulation, only departmental padlocks with a unique key are acceptable but in terms of best practice, the coded seal on the lockout box (with the code on the lockout placard) can be a safe approach to lockout because personnel will know if the seal is removed. Moreover, use of lockout boxes and filling out a logbook can help organizations to transfer information between two shifts.

Almost all the organizations (9/13) used neither a master key nor a double key and their practice was to cut the lockout device. Only two organizations used a master key. This finding shows that most of the organizations were not aware of the management of the double key (i.e. where to keep it, when to utilize it, who keeps it, who utilizes it).

The Canadian standard states that padlocks should only be removed by the authorized employee who affixed the lock. In the case of absence of the authorized employee, the employer is required to have an emergency removal procedure. All the lockout programs covered circumstances that require the application of the lockout removal procedure in case of forgetting or losing a key, or absence of the authorized employee. In practice the organizations were compliant with the Canadian standard and Quebec’s regulation. Although they rarely had to use the emergency removal procedure, they applied the emergency removal steps which are to: (i) attempt to communicate with the worker who forgets his padlock (13/13), (ii) ask him if he is still in the workplace or return to the workplace (13/13), (iii) carefully inspect and assess the condition of the equipment and the environment (13/13), (iv) be accompanied by for a witness to be present when the lockout devices are removed (11/13), (v) proceed to the padlock removal (13/13), (vi) record the withdrawal by the designated person and keep the document for at least one year (10/13).

Taken together, management of special cases was under control in most of the organizations. This finding is different from Poisson and Chinniah (2016) who found that the lockout removal process in the sawmill industry was poorly documented and also no lockout program addressed the need to follow instructions with regard to padlock removal in sawmills.

4.4.3 Other methods of control of hazardous energies

The use of alternative methods to control of hazardous energies was needed in nearly all the organizations. Therefore, it was necessary to understand what methods were used, and how the organizations used them in order to comply with the Canadian standard and Quebec regulation.

The main reasons for using alternative methods to lockout were either that tasks are integral to production (12/13) or the need for equipment to be energized (10/13). Activities such as troubleshooting, unjamming and cleaning were the activities in which alternative methods to lock-out were most frequently used. However, the criteria for deciding whether to use lockout or alternative methods were rarely formally defined.

The organizations used alternative methods such as: (i) moveable interlocked guards in an activated open position secured by a padlock; (ii) safety devices (curtain, laser, camera, safety mats) locked in the activated position (e.g. by putting a piece of metal in front of the beam of the optical curtain and blocking with a personal padlock) (see Figure 4-3); (iii) covers on control panels which are closed and locked; (iv) emergency stop buttons with lockable caps, which require the emergency button to be activated (see Figure 4-4); (iv) and placing control units such as pendants for robots inside locked boxes. Most of the organizations reported that when the alternative method involved the equipment’s control systems, they did not validate the reliability of the alternative method using the appropriate standard (ISO 13849-1, 2015).

In addition, according to the ROHS regulation (Art. 188.2), lockout may not be applied: (i) where a machine has a single energy source and where there remains no residual energy after the machine is unplugged; and (ii) where work is carried out in the danger zone of a machine that has a specific control mode to become inoperative. Only three organizations dealt with these exclusions through the alternative method procedure (2/13) or by means of the work permit (1/13). For example, two organizations used the control mode with reduced speed control for robots.

In terms of working under voltage, more than half of the organizations (7/13) used PPE as an alternative method to lock-out. According to National Fire Protection Association [NFPA] (NFPA 70E (2015) and CSA Z432 (2016) standards, troubleshooting tasks on live voltage are possible after a risk analysis and if the worker uses proper PPE and proper tools.

Figure 4-3 Safety curtain that could be locked in the activated position

Figure 4-4 Pad-lockable cap to an emergency stop button

Although six organizations had safety instructions (3/13), exemption permits (2/13) or placards (1/13) for the alternative methods to lockout of specific machines or tasks, most of the required elements and steps of the application of procedures were missing.

Overall, risk analysis for alternative methods was problematic in most of the organizations. For example, only three organizations performed the risk analysis to validate the use of alternative methods to lockout for a specific task by means of a risk matrix (2/13) and a risk graph (1/13). Two organizations intended to carry out the risk analysis for the alternative methods in the current year. Risk estimation tools for machines have been analyzed in the literature (Cagno et al., 2000; Chinniah et al., 2011; Gauthier et al., 2012; ISO/TR 14121-2, 2012).

Although the use of alternative methods to lockout is increasing in the organizations studied, practice was not compliant with the standard and regulation, especially for risk analysis. As yet, alternative methods to lockout do not appear to be fully understood and formally implemented.

Table 4-7 summarizes key shortcomings and recommendation to address them.

Table 4-7 Shortcomings observed and possible improvements concerning alternative methods to lockout

Standard and regulation on lockout	Lockout programs	Actual lockout practices	Recommendation or possible improvements
Minor tool changes, servicing activities and adjustments do not require lockout to be applied so long as they are "routine, repetitive, and integral to the use of the equipment" for production (CSA Z460, clause 7.4)	Alternative methods mentioned in only 5/13 programs	More than half of the organizations (7/13) had no written procedures/instruction for the alternative methods; the rest had incomplete procedures.	Add alternative methods in the programs and provide a general procedure, including all the steps. Identify the task can be exempted from lockout according to North American standards. Work permits are not appropriate procedures for the alternative methods since they present the control and the authorization of interventions
Ensure the equivalent safety of methods by analyzing the following (ROHS, art. 188.4): (1) The machine features; (2) Identifying risks when using the machine…	- Not mentioned in the lockout programs	- Application of alternative methods without risk assessment (11/13), in fact, they carried out the risk assessment only for production tasks on machines	- Risk assessment and analysis is necessary before the use of alternative methods and also to select the appropriate measure. Validation of control system reliability (according to ISO13849) when it is involved in alternative methods
… (3) Risk estimation; (4) The estimate of the level of risk reduction and the assessment of residual risks… … (5) Document the results of the analysis	- Not mentioned in the lockout programs - No formal instructions or requirements in the programs	- Using inappropriate tools for risk estimation - Lack of documentation of the application of alternative methods to lockout (12/13)	- Explain risk estimation for alternative methods in the lockout program. Use risk estimation tool such as matrices - Document the application of alternative methods, sign the procedures or permits for keeping purposes

Table 4-7 Shortcomings observed and possible improvements concerning alternative methods to lockout (cont.)

Require task-specific training (ROHS art. 188.8)	No formal instructions in the programs	Lack of specific training in terms of alternative methods to lockout	Add specific training related to the application of alternative methods in the training program for authorized/affected workers
Lockout exemptions on specific equipment/machines (ROHS art. 188.2). (As explained earlier in the subsection)	No formal instructions in the programs	Using the jog mode for the equipment excluded from lockout, or using the stop button (6/13)	Add specific instructions for these equipment/machines in the program. Use of technical solutions (e.g. operating machines equipped with a specific control mode at reduced speed, under reduced force, step-by-step or by means of a hold to run control device)

4.4.4 Training of workers on lockout

In this section, the key elements related to employee training/retraining and record keeping were assessed against the Canadian standard and Quebec regulation expectations.

Only one organization had no training program for employees and the last training was carried out when its lockout program was revised a long time ago. The training in practically all the organizations (12/13) was initially theoretical (e.g. a general lockout procedure, hardware). Advanced training was also conducted in five organizations. The lockout program was a part of the training material for new employees in only four organizations. In practice, the lockout program was not used or read by employees.

Demirkesen and Arditi (2015) showed the important factors in safety training: e.g. use of visual aids, providing feedback, and worker learning assessment. Ray et al. (1997) assessed the efficacy of the components of a behavioral safety program through observation on operations such as lockout procedures performed by two groups (experimental and control groups). They compared the groups at four different points in time: at baseline; after classroom training only; after training and receiving feedback; and after training, feedback and the addition of safety goals. The authors showed no improvement in the safety behavior of the experimental group with training only, until feedback was provided. Furthermore, they indicated a significantly higher safety level in the workplace when feedback combined with goal setting. Taking these findings into account, more than fifty percent of organizations (7/13) stated that they had an assessment at the end of training which contained a written test (questionnaire /checklist) (6/13) or an evaluation form relating to the application of lockout (1/13). Furthermore, training was carried out internally in 10 out of 13 organizations.

Almost all the organizations (12/13) kept a list of the employees in order to know who was trained and when. The frequency of upgrading training was different in each organization: every 6 months (1/13), annually (2/13), every 2 years (2/13), every 3 years (3/13) and unforeseen (3/13). Moreover, 11 organizations stated that the requirements of retraining were recognized through the outputs of OHS audits or regular inspections of safety including lockout. Kelley (2001) showed that training/ retraining was an important factor for the workers who apply lockout.

In practice, training was better carried out than the lockout program suggested. Taken together, training and record keeping in the organizations were almost compliant with the Canadian standard and ROHS regulation. Table 4-8 presents some shortcomings and actions to improve training programs.

Table 4-8 Shortcomings observed and possible improvements concerning the Training.

Standard and regulation on lockout	Lockout programs	Actual lockout practices	Recommendation or possible improvements
Effective training (CSA Z460, clause 7.5.2):			
- Training includes samples of machine-specific procedures and enables personnel to interpret and implement procedures (such as practical demonstrated applications)	- Training just mentioned in 6/13 programs	- Lack of practical training at 8/13 organizations	- Add training and its requirements in the program. Use of more visual aids in theoretical training and conduct the practical training at worksites
		- The lockout program was not part of training in 9/13 organizations	- The lockout program is a useful text during training sessions and can be given to new employees. It will avoid workers repeating mistakes made by peers and will help empower them. But it should not replace proper communication and training on lockout
- Retraining must be provided annually to re-establish employee proficiency with control methods and procedures	- Not mentioned in 7/13 programs	- Unforeseen frequency of retraining (3/13) and the content thereof (8/13)	- Periodic re-training is required for all the affected and authorized employees whenever there is a change in job assignments, a change in machines, equipment, or processes that present a new hazard, a change in the energy control procedures, or a revision of control methods (not to exceed 3 years). The content of this refresher training is based on known hazards and risk assessment for the planned work activities and working conditions
- Documentation certifies that employee training has been accomplished and is being kept up-to-date	- Not mentioned in 8/13 programs	- Documentation of retraining was not complete in most of the organizations	- Document and record each employee's name, number of hours, and dates of training

4.4.5 Sub-contracting/ external services

The management of subcontractors (specifically external services or contractor personnel) were investigated and the results are presented in this section. The aim was to determine the extent to which the relationship between, the responsibilities of, and obligations of employers and subcontractors are in compliance with the Canadian standard and Quebec regulation.

The activities outsourced by most of the organizations were maintenance, electrical works, ventilation systems and new projects. In most of the organizations (10/13), sub-contractors had to obtain written authorization before undertaking work in hazardous areas. Moreover, in all of the organizations, the subcontractor's hardware was used when applying lockout or alternative methods.

In almost half of the organizations (6/13) subcontractors had been trained on lockout or other energy control methods. In three organizations subcontractors were considered to be specialists in the equipment concerned, and the organizations justified the lack of supervision on this basis. In fact, this finding shows that the validation of subcontractors' qualifications and competencies was neglected. Moreover, in the case of several existing subcontractors, coordination of rules and responsibilities were compromised in a number of organizations (8 /13).

Furthermore, only five organizations had a training program related to the application of lockout for their subcontractor. Two organizations utilized specific software to manage sub-contractors, which enabled them to follow subcontractors' qualifications, especially management of training and skills.

Nunes (2012) studied the link between subcontracting and occupational health and safety and showed that supervision, training, roles and responsibilities, communication lines and cultural and linguistic barriers can be problematic in the management and control of contractors. The author recognized that exposure to hazardous situations during outsourced activities can be prevented by effective communication between host and contractors, long-term cooperation, knowledge sharing, effective supervision and adequate training. Our findings suggest weaknesses in these areas in the organizations studied.

The level of control (i.e. supervision and audit of subcontractors) varied from one organization to another. Nine organizations claimed that they audited their subcontractors' lockout activities, but in practice they did not have a specific audit tool for that. In four organizations, subcontractors signed the lockout procedure sheet (or placards) and this was the simple audit point for organizations. There was no documentation in terms of the audit of subcontractors' lockout activities. In spite of the fact that subcontractors were expected to follow the host procedures in most of the organizations, the audit was missing and therefore problems could arise if subcontractors followed their own procedures.

In summary, the management of subcontractors in almost all the organizations was not fully compliant with either the Canadian standard or the ROHS regulation. Recommendations to address shortcomings in this area are presented in Table 4-9.

Table 4-9 Shortcomings observed and possible improvements concerning the subcontracting/external services.

Standard and regulation on lockout	Lockout programs	Actual lockout practices	Recommendation or possible improvements
Supervision of the subcontractor's activities. Ensure that self-employed worker will apply an energy control method that complies with the regulation (ROHS, art. 188.9)	Not mentioned in the programs	Inadequacies regarding supervision of the subcontractor's lockout activities, no audit tool, and no documentation.	The lockout program has to meet all the requirements. Start an audit of subcontractors and document the outcomes. Moreover, the presence of the supervisor for the verification step (i.e. verifying that energy was isolated) of the application of lockout (carried out by the subcontractor) can enhance supervision
Coordination and communication between host and sub-contractors: - In the case of more employers or self-employed workers, determine their respective roles and their means of communication (ROHS, art. 188.10)	- Communication plan mentioned in only 6/13 programs. Roles and responsibilities of subcontractors were missing in 4/13 programs	- Lack of coordination of the roles and responsibilities (8/13 organizations)	- Add all the requirements for the lockout program. For example, adding subcontractor padlocks to internally prepared lockout boxes. Require to sign the placards

Table 4-9 Shortcomings observed and possible improvements concerning the subcontracting/external (cont.)

- Obtain written authorization from the employer who has authority over the establishment before undertaking work in the danger zone of a machine (ROHS, art. 188.9)	- Not mentioned in the programs	- Missing in 3 organizations	- Prepare a written authorization before undertaking work in the hazardous areas
Outside employees must be trained and possess the applicable qualifications to perform work covered by this Standard (CSA Z460, clause 7.3.6)	Only 4/13 programs mentioned the validation of subcontractor's competencies	Absence of verification of subcontractor's training in 7/13 organizations	Have specific training for new subcontractors and verify the actual integration of the knowledge acquired during training through observation of the subcontractor's activities. The observation of the subcontractors' work also can help to check that they are well trained

4.4.6 Audit/Inspection

Audit of the lockout program, procedures, and the application of lockout and alternative methods were verified and are presented in this section.

Over half of the organizations (9/13) stated that they carried out periodically an audit of the lockout program, an audit of the lockout procedures and/or an audit of the application of lockout. However, we found only one organization implemented all these types of audits and had distinct checklists (tools) for them. In practice the lockout audit was part of the general safety audit in most of the organizations and the result of safety audits was not used specifically for lockout. Moreover, the level of accuracy and completeness of these audits was different in each organization. For example, the reasons for auditing the lockout program or application of lockout were not clear in most of the organizations. Only one program mentioned the need to deal with the nonconformities identified through the audit as the main reason to perform audits. Participants in more than half of the organizations (7/13) claimed that the audit findings were used for continuous improvement (4/13) and corrective action (3/13). However, it was not possible to confirm this as audit results were available and documented in only two organizations.

It is important that organizations use audit findings to modify and update the lockout program, procedures and application of lockout in order to ensure that these are fully compliant with the Canadian standard and ROHS regulation. Grund (1995) stated that the implementation of lockout is not sufficient and the vigilance of organizations is important to ensure that: (i) lockout procedures are adequate, effective and used; and (ii) employees are trained. This author advises that the absence of incidents for several months or years does not automatically indicate that the lockout is being applied. Audits allow organizations to evaluate lockout and develop realistic portraits of internal practices. They also allow for continuous improvement of lockout, identifying problems and correcting them.

Of the organizations studied, most (8/13) stated that they had tools for audit and inspection of lockout. However, all the available tools were simple checklists which contained only a few questions about lockout. For example, we found only three tools in which there were a few questions to verify the elements of a lockout program. This finding shows that almost all the organizations had no appropriate audit tools for lockout.

The standard CSA Z460 explains that audits must be designed to correct any observed deviations or inadequacies. However, specific audit tools are not mentioned in the standard. OSHA (1999) states that self-assessment auditing is an effective method for organizations to monitor and improve safety. Esposito (2009) advocates questionnaires and checklists as audit tools to define minimum expectations for evaluating safety measures. Robson and Bigelow (2010) have shown that audit tools must be valid and reliable so that practitioners can make appropriate and effective decisions.

Although there was some auditing of safety in the organizations studied, this was not fully compliant with the expectations of Canadian standard and thus it remains problematic. Table 4-10 presents recommendations concerning audits of lockout.

Table 4-10 Shortcomings observed and possible improvements concerning the audits of lockout.

Standard and regulation on lockout	Lockout programs	Actual lockout practices	Recommendation or possible improvements
The audit of program elements must be part of a lockout program (CSA Z460, clause 7.3.1)	Not mentioned in 8/13 lockout programs	- Four organizations with no audits of lockout, 7/13 performed general audits not specifically for lockout. The reasons for audits were not clear (9/13)	- Add audit with its requirements in the lockout program - Identify the scope of audits and define the reasons (for example, update the program, change or modify the machine/equipment /process, and employees training or the failures observed, respectively, can be the reasons for the audit of the program, procedures, and the application of lockout) - Identify requirement and expectation against standard and regulation. Define who is responsible for the audits
		- Five organizations had no audit tools and the rest had simple audit tools	- Using a self-audit method, define valid questionnaire and checklists
Annual auditing of written procedures and authorized personnel is necessary. Documentation of audit records shall be maintained for at least three years (CSA Z460, clause 7.6.3; ROHS, art. 188.5)	Not mentioned in 10/13 lockout program	- Frequency of audits was not determined in 5/13 organizations	- Auditing must be conducted at least annually and documentation shall be maintained for at least three years. Periodic inspections of the application of lockout, in particular, every time a machine is altered or a failure is reported
		- Absence of documentation of results in 11/13 organizations	- Record all the audit results and outcomes (document the process, for example, when it was carried out, by whom, number of non-compliances, etc.), and also share the results/feedbacks with workers and supervisors to implement corrections.

4.5 Conclusions

Although a fundamental part of the safety of machinery in many countries, lockout on machinery has not been studied extensively. Organizations face challenges when they have to apply lockout as described in relevant regulations and standards. The reasons are often a mixture of technical, organizational and human behavior aspects. For the first time, a study on the application of lockout on machinery in organizations across different industries was carried out. Nine out of the 13 organizations studied, were medium or large-sized businesses (i.e. with more than 100 employees) and they respectively applied 30-400 lockout procedures every week to their approximately 50-4000 machines. The objective of this qualitative research was to understand the application of lockout and alternative methods in these organizations as well as to identify challenges and shortcomings when compared to Canadian standards and regulatory requirements. The exhaustive questionnaire used by the researchers enabled a thorough examination of lockout in the 13 organizations through using data from interviews, document review and site observations. Our findings show that the lockout program (i.e. document describing lockout) is not always an accurate measure of actual lockout practices in organizations. In other words, the study showed that the actual lockout practices were better than what was explained in the lockout programs for most of the items which were analyzed. As such, labor inspectors and external auditors cannot rely on written programs alone to evaluate lockout practices in an organization.

Moreover, we found some good practices such as: (i) the systematic use of a lockout box as a structural element for the continuity of lockout, the supervision of subcontractors and for audits; (ii) facilitating the access of employees to lockout procedures by placing lockout the placards next to the equipment/machines; and (iii) improving safety culture through training of employees and progressive incentive and disciplinary measures.

Although we found positive results regarding lockout and alternative methods in most of the organizations, considerable improvements are needed. Hence the study detailed shortcomings and proposed recommendations to address these, mostly for the content of the lockout program, application of alternative methods, management of subcontractors and conduct of audits which were problematic in the organizations visited. It is important to implement the proposed recommendations to ensure that lockout and alternative methods are applied properly. In summary, the main shortcomings were found to be: (i) incomplete lockout programs (e.g. audit, alternative methods, risk analysis, subcontractor selection and supervision were neglected); (ii) missing steps in general lockout procedures (e.g. no identification and location of any control device of the machine); (iii) neglecting to read the placards; (iv) applying alternative methods without risk assessment as well as lack of reasons and criteria to require alternative methods to lockout; (v) absence of a training program (e.g. lack of training for the alternative methods and lockout program); (vi) absence of supervision of subcontractors and coordination of the roles and responsibilities; and (vii) lack of appropriate audit tools and documentation of audit results. It is believed that the findings of this research can enrich the understanding and the practice of organizations, occupational health and safety specialists, as well as safety committees in relation to lockout.

Acknowledgements

The authors wish to thank the organizations that agreed to participate in this study and authorized the use of the photographs. Furthermore, the authors wish to thank the anonymous reviewers for their careful reading of this manuscript and their many insightful comments and suggestions. They also wish to thank the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), as well as NSERC for funding this research. This study was conducted as part of a project approved by the Polytechnique Montréal’s committee on the ethical conduct of research involving human subjects.

CHAPTER 5 ARTICLE 2: HAZARDOUS ENERGY CONTROL ON MACHINERY: UNDERSTANDING THE USE OF ALTERNATIVE METHODS TO LOCKOUT

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This article was published in Safety Science 118 (2019): 519-529.

Abstract: National standards and regulations in many countries establish requirements for controlling hazardous energy related to machinery that could cause accidents linked to the release of these energies, unexpected energization or start-up of machines or equipment. These standards and regulations describe alternative methods to lockout and the conditions for using them. The purpose of the study is to understand the application of alternative methods to lockout and investigate how they are implemented in accordance with the Canadian standard and regulation in force. Therefore, in this qualitative research, the application of alternative methods for control of hazardous energies was studied in 14 organizations in Quebec (Canada). A questionnaire that included 15 questions on the application of alternative methods was designed and used. In each organization, the research team conducted a group interview, collected additional data from observations and documentation, and completed the questionnaire. Results indicated the need to increase knowledge about alternative methods to lockout and the regulation. Actual practices in the organizations visited demonstrated that alternative methods were used without being compliant with the standard and regulation. A risk assessment was not carried out before applying an alternative method. Moreover, a general working procedure for alternative methods was missing or incomplete in all the organizations. There was a lack of training in alternative methods as well as lack of audit/inspections of their application. In this regard, recommendations for addressing identified shortcomings are proposed.

Keywords: Alternative methods to lockout, Hazardous energy, Risk assessment, Machinery safety

5.1 Introduction

Workers are exposed to hazards when they intervene on machinery during different working activities (e.g. installation, operation, maintenance, troubleshooting, repairs, adjustments, set-up, production disruptions, cleaning, and dismantling). The US Bureau of Labor Statistics (BLS, 2016) reported that in 2015, a total of 722 fatal work injuries occurred as a result of contact with objects and equipment in the U.S. Moreover, failure to control hazardous energy accounts for nearly 10 percent of the serious accidents in many industries in the U.S. It was also the fifth most cited Occupational Safety and Health Administration (OSHA) violation in 2015 and 2016 (OSHA, 2016; OSHA, 2015). In Quebec, where this study took place, four deaths and 1000 accidents on average occur annually due to either poor, or the absence of, lockout procedures (CNESST, 2016). These deaths represented approximately 10% of work-related fatalities over the period.

5.1.1 Primary method for controlling hazardous energies

The Canadian Standards Association [CSA] (CSA Z460, 2013) in Canada and American National Standards Institute [ANSI] (ANSI/ASSE Z244.1, 2016) in the U.S. describe the requirements for the control of hazardous energies which is referred to as lockout. Lockout is used during the maintenance of machines, equipment, and processes. It is defined as a placement of a lockout device on an energy-isolating device, in accordance with an established procedure, ensuring that the energy-isolating device and the equipment being controlled cannot be operated until the lockout device is removed. The basic steps of the lockout procedure are described in OSHA 29 CFR 1910.147 (1989) and Quebec's Regulation respecting Occupational Health and Safety (ROHS, 2017). In all of the standards and regulations mentioned above, lockout is the primary method of hazardous energy control.

Moreover, worldwide standards like the international standard ISO 14118 (2017), the European standard EN 1037:1995+A1 (2008) and also other nationwide regulations/standards [e.g., Australia: AS 4024.1603 (2006: R2014); Singapore: SS 571 (2011); UK: PUWER (1998) regulation 19; Germany: DEU (2015: R-101566)] provide guidance on the control of hazardous energy.

5.1.2 Alternative methods for controlling hazardous energies

Despite the fact that lockout is the primary hazardous energy control method, North American standards and regulations state that traditional lockout is not always practicable (OSHA 29 CFR 1910.147, 1989; ANSI/ASSE Z244.1, 2016; CSA Z460, 2013; ROHS, 2017). Those standards and regulations address concerns of decision makers (i.e. safety practitioners) in order to determine which method (i.e. lockout, alternative methods or a combination of these) is appropriate to control of hazardous energy as well as to describe the conditions surrounding alternative methods. However, decision making is not always easy since the standards and regulations provide general guidelines that are not identical and interpretation can be very subjective. For example, Main and Grund (2017) mentioned that since 1982, ANSI/ASSE Z244.1 has evolved several times, especially on the subject of alternative methods to lockout, whereas OSHA's regulation has been unchanged for more than 25 years. The authors stated the opinion that "safety progress might be defeated by relying upon expectations that date back to 1989". The general requirements for applying alternative methods to lockout in North America are briefly described in Table 5-1.

Table 5-1 Alternative methods to lockout in North American standards and regulations

	ANSI/ASSE Z244.1, 2016	CSA Z460, 2013	OSHA 29 CFR 1910.147, 1989	Quebec's ROHS, 2017
Alternative methods vs Lockout	Lockout is the primary method	Lockout is the primary method	Lockout is the primary method	Lockout is the primary method
Information about managing alternative methods	More detailed	More detailed	Less detailed	Moderately detailed
Alternative method and Risk assessment	Risk assessment is mandatory before selecting and using alternative methods	Risk assessment is mandatory before selecting and using alternative methods	Not mentioned in the regulation	Risk assessment is mandatory before selecting and using alternative methods
Application of Alternative method	For: (i) hazardous energy is required to do the task; (ii) lockout is not feasible or practicable; (iii) a documented risk assessment shows the task can be performed with acceptable risk; (iv) inherent hazards (e.g., thermal, radiation) are unable to be controlled using lockout or tagout; (v) energy is required to maintain equipment in a safe state; (vi) repetitive cycling of an energy isolation device compromises its safe functioning; or (vii) the operation of a standard energy isolation device creates an additional hazard	For appropriate tasks (to be considered integral to production) exhibit most of the following characteristics: (i) of short duration; (ii) relatively minor in nature; (iii) occurring frequently during the shift or production day; (iv) usually performed by operators, set-up persons, and maintenance personnel; (v) represent predetermined cyclical activities; (vi) minimally interrupt the operation of the production process; (vii) exist even when optimal operating levels are achieved; and (viii) require task-specific personnel training	For minor tool changes and adjustments, and other minor servicing activities, which take place during normal production operations, are routine, repetitive, and integral to the use of equipment for production, and then, work is performed using alternative protective measures, which provide effective employee protection	For undertaking any work in the danger zone of a machine (e.g. erecting, installing, adjusting, inspecting, unjamming, setting up, decommissioning, maintaining, dismantling, cleaning, servicing, refurbishing, repairing, altering or unlocking), when there is the equivalent safety of the alternative method to lockout through risk assessment

5.1.2.1 American and Canadian standards and regulations

Table 1 simply presents a brief comparison of North American standards and regulations with regards to alternative methods since drawing a detailed comparison of them or worldwide standards is not the objective of the study. For example, according to the OSHA, servicing and maintenance activities conducted during normal production operations are not included in regulation 29 CFR 1910.147 (the control of hazardous energy [lockout/tagout]) if safeguarding prevents workers' exposure to hazards (OSHA 29 CFR 1910.147, 1989).

ANSI/ASSE Z244.1 (2016) explains details of alternative methods to lockout and states that the rapid growth of technology continues to require different methods and techniques for safeguarding workers from the unexpected release of hazardous energy. It recognizes that zero risk is not an operative reality and thus provides clear guidelines for companies on when and how alternative methods may be used to provide effective protection.

The Canadian standard, CSA Z460 (2013), is in line with ANSI/ASSE Z244.1 (2016) and states that when lockout affects the tasks that are integral to the production process by design or traditional lockout prohibits the completion of specific tasks, other hazardous energy control methods shall be used. The Canadian standard is not mandatory in different provinces, but represents the state of the art in hazardous energy control.

Moreover, different regulations on lockout exist in the provinces in Canada. In Quebec, where the study was carried out, regulations on lockout (ROHS) were strengthened in 2016. Obligations to apply lockout or other methods are now explicit, more detailed. Lockout is the preferred method, but using alternative methods through a risk assessment (that ensures equivalent safety) is now possible when lockout cannot be applied (ROHS, 2017).

5.1.2.2 Risk assessment and effectiveness of alternative methods

North American standards, i.e. CSA Z460 (2013) and ANSI/ASSE Z244.1 (2016), require performing a risk assessment (i.e. documented risk assessment) when alternative methods to lockout are applied in order to determine whether these methods produce an acceptable level of risk. In general, the risk assessment process comprises the several steps: (i) the specification of the limits of the machine; (ii) hazard identification; (iii) risk estimation (i.e. defining likely severity of harm and the probability of its occurrence); and (iv) risk evaluation (i.e. make a judgment, based on the results of risk estimation, about whether the risk reduction objectives with the acceptable risk level are achieved). Risk assessment methods can be found in ANSI B11.0 (2015), International Organization for Standardization [ISO] (ISO 12100, 2010), Semiconductor Equipment and Materials Institute [SEMI] (SEMI S10, 2010), ANSI/ASSE Z10 (2012), ISO/IEC 31010 (2009), ISO/TR 14121-2 (2012), CSA Z1002 (2012) and others. In addition to the standards, several studies proposed methods for the risk assessment of machinery, for example, risk assessment matrix (Aneziris et al., 2013; Chinniah et al., 2011; Etherton et al., 2008; Gauthier et al., 2012). It should be noted that risk assessment is a subjective process and given that, ranking risks is also subjective. Manuele (2005) and Caputo et al. (2013) showed that the process of risk estimation and reduction is subjective and is based on the analyst' opinion, the knowledge of the people and a personal judgment.

The results of the risk assessment process are used in implementing the process of risk reduction in order to select and use appropriate alternative methods. ANSI/ASSE Z244.1 (2016) and CSA Z460 (2013) present a hierarchical process for the selection of feasible risk reduction measures (i.e. other hazardous energy control methods) in the following order of preference: (i) eliminate the hazard through design or substitution; (ii) engineered safeguards and safeguarding devices (e.g. fixed guards, moveable guards with interlock, presence sensing devices, two-hand control devices and etc.); (iii) awareness devices and alerting techniques; (iv) safe work procedures and training; and (v) use of personal protective equipment (PPE). The similar process is also found in other studies and standards (Chinniah et al., 2007; Manuele, 2005; ANSI B11-TR3, 2000; CSA Z432, 2016; ISO 12100, 2010; Zoubek, 2015).

According to ANSI B11.0 (2015), an alternative method must provide an acceptable risk level. If risk is considered unacceptable, then the risk reduction process must be carried and risk must be reassessed and repeated. Indeed, uncertainty in risk assessment poses problems for the effectiveness of alternative methods. To increase the effectiveness, alternative methods shall consist of the following parameters as applicable: (i) practicability/justification analysis; (ii) risk assessment based on the tasks being performed; (iii) industry best practices/methods; (iv) architecture/structure; (v) using well-tried components; (vi) using well-tried designs; (vii) common cause failure; (viii) fault tolerance; (ix) exclusivity of control; (x) tamper resistance, (xi) program to support; (xii) procedures in place; (xiii) periodic checking and testing; and (xiv) review by a qualified person (ANSI/ASSE Z244.1, 2016). The effectiveness of alternative safeguards was also defined in several studies (Backström & Döös, 2000; Booth, 1979; Caputo et al., 2013; Gauthier & Charron, 2002).

5.1.2.3 A review of studies on alternative methods reported in the literature

A review of the literature demonstrates that studies on alternative methods are limited to a specific sector, method, task, machine or equipment.

For example, Poisson and Chinniah (2015, 2016) demonstrated that in order for troubleshooting on machinery in sawmills, permits as alternatives to lockout were issued without any risk assessment. Although special tools (e.g., a gaff to unjam logs on conveyors or a belt as PPE) were used for lockout exemptions, risk analysis was not applied to ensure that other hazards did not exist. None of the sawmills had an electrical interlocking system to stop the machine during access when guards were opened.

Burlet-Vienney et al. (2017b) showed that the preferred procedure for major work on mobile equipment should be lockout. However, it is important to identify types of work that will require a specific position for the equipment (e.g., raised bed), a specific energy source (e.g., for diagnostic purposes) or a specific procedure. Maintenance or service of this kind will require alternative methods.

Finally, Chinniah et al. (2017b) evaluated the safety of workers who used horizontal plastic injection moulding machines with auxiliary equipment by a risk assessment for maintenance and production tasks in eight companies. Two typical means of risk reduction were identified: (i) the use of a partial lockout procedure, whereby a padlock was attached to the console or a guard to avoid start-up by a third party; (ii) the use of safety functions to access the mould area such as interlocked guards in open position with a padlock, pressure-sensitive floors for detecting any presence in the mould area (the use of presence detectors in the mould area was limited), and an emergency stop function. Lockout was used only for major maintenance and services. The study revealed that companies encountered difficulties in evaluating the reliability of the safety functions that were used during interventions due to insufficient knowledge of the standards in force, for example, ISO 13849-1 (2015).

5.1.3 Originality and Objective

The research literature on alternative methods is sparse; this may be because the focus has been on lockout and the official use of an alternative to lockout has been restricted. For the first time, the application of lockout in different organizations was investigated through a qualitative study (Karimi et al., 2018). This previous study built a good picture of how lockout was applied in organizations in Quebec. As such, results related to alternative methods were presented only briefly. In this paper, as the second part of the previous study, the main objective is the focus on alternative methods in order to gain a deeper understanding of how they are implemented in comparison to the standard and regulation in force (i.e. CSA Z460, 2013; ROHS, 2017). Furthermore, gaps and shortcomings are identified, and recommendations to improve practices are proposed.

5.2 Method

5.2.1 Selection and recruitment of organizations

This study used the same sample (the same organizations and participants) and the same data as Karimi et al. (2018) plus one more organization. However, data related to alternative methods to lockout have been fully utilized in this paper.

In the end, 14 organizations were recruited in the province of Quebec (Canada) in 2017 and a qualitative analysis was conducted. Convenience sampling was selected for this study because sample sizes are typically small in qualitative research. Indeed, that type of research is intended to achieve the depth of understanding of phenomena (Bricki & Green, 2007; Patton, 2002). To explore a range of work situations, a diverse range of organizations was recruited (Table 5-2). In the course of recruiting, the following criteria were used:

1. The organizations must have had a lockout program for at least five years and apply lockout procedures on machinery.

2. Ideally, the organization should use alternatives to lockout and, it should have already conducted an audit of its lockout program and its application (e.g. application of alternative methods).

3. Organizations with no previous experience in the application lockout were excluded from the study.

Table 5-2 General information of 14 organizations in the study.

Organization	**Sector**	**Size (Number of employees: <100; <500; ≥500)**	**Safety committee**	**Number of items of machinery/equipment (approximately)**
A	Chemical industry	<100	Yes	125
B	Chemical industry	<100	No	50
C	Food industry	<500	Yes	1000
D	Pulp and Paper	<500	Yes	4000
E	Plastic industry	<500	Yes	200
F	Food industry	<500	Yes	500
G	Plastic industry	<100	Yes	100
H	Fabrication	<500	Yes	800
I	Recycling	<100	Yes	6
J	Printing	<500	Yes	100
K	Horticulture and agriculture	<500	Yes	50
L	Aerospace	≥500	Yes	1300
M	Health service	≥500	Yes	450
N	Health service	≥500	Yes	200

5.2.2 Data collection and analysis

Data collection was carried out in the same way as Karimi et al. (2018). Indeed, during the visit from each organization, the data were collected through an interview, observations and documentation collected (e.g. written lockout program, lockout placards, audit tools and results of the audits, lockout training documents). To conduct the interviews, a valid questionnaire was designed based on the requirements of the latest version of the regulation in force in Quebec (ROHS, 2017) and the Canadian standard (CSA Z460, 2013). Briefly, it included six items, namely: (i) general lockout program; (ii) application of lockout; (iii) other methods for the control of hazardous energies; (iv) sub-contractor; (v) training; and (vi) audit/inspections. More details were elaborated in Karimi et al. (2018). In this paper, mainly the third item of the questionnaire and the 15 related questions (including some related questions of the fifth and sixth items) were used (Table 5-3).

The quality of data collected is increased by using trained interviewers and an appropriate interview schedule (Bricki & Green, 2007; Patton, 2005). Hence, in each organization visited, a group interview (with a technician/operator and a safety supervisor) was conducted by two skilled researchers who completed the questionnaire concurrently (but independently). Finally, and in order for the analysis of data, the data from the 14 organizations were handled and analyzed through the following steps:

1. After each visit, the interview notes from the two researchers were transcribed and then the questionnaire was finalized by combining the interview notes, the observations and the collected documents.

2. Using a Microsoft Excel© file, the data from each organization were categorized in order to facilitate qualitative analysis (Meyer & Avery, 2009). Each tab corresponds to the items listed in Table 5-3. It includes 15 columns based on questions of the questionnaire and also 14 rows assigned to the organizations visited. All answers of each interview were entered in the related cells.

3. The analysis revealed the challenges experienced by the organizations visited related to the application of other methods of control of hazardous energies. The analyses also highlighted how

the organizations dealt with them to ensure compliance with the current regulation (ROHS, 2017) and standard (CSA Z460, 2013).

4. Shortcomings were identified and recommendations and possible improvements were proposed based on the shortcomings and issues observed in actual practices in the use of alternative methods to lockout.

Table 5-3 Questions on alternative methods of control of hazardous energies in the questionnaire

Questions	**Reference used as guidelines when designing the questionnaire**
Do you have interventions where you do not lock out and use alternative methods? How? What type of interventions?	
What criteria are used to target tasks that require the application of other methods rather than lockout procedure? (a need for energy, an integral part of the production process, etc.)	ROHS, art. 188.2 CSA Z460, S.7.4.2
What are the alternative methods to lock-out that you use? (i.e. moveable interlocked guard, emergency stop button which is locked with a padlock, safety device locked in the activated position, PPE, etc.)	ROHS, art. 189.1 CSA Z460, S.7.4.2
If the alternative method involves the control system, do you validate its reliability? How?	ISO 13849 CSA Z460
Do you have a written procedure for alternative methods to lock-out? What is the content of the written procedure?	CSA Z460, S.7.4.2
What measures have been taken to facilitate understanding of procedures and avoid errors (e.g. photo, pictogram)? How are they made available in the workplace where the work is done?	ROHS, art. 188.5
How is the application of alternative procedures to lockout recorded?	ROHS, art. 188.5
To choose the alternative method to lockout, have you performed a risk analysis?	ROHS, art. 188.4 CSA Z460, S.7.4.2

Table 5-3 Questions on alternative methods of control of hazardous energies in the questionnaire (cont.)

Are the results of this risk analysis documented? (What results?)	ROHS, art. 188.4 CSA Z460, S.7.4.2
What tool do you use for risk analysis? (Matrix, checklist, risk graph)	ROHS, art. 188.4
Who is involved in the process of risk assessment and reduction linked to alternative methods?	ROHS, art. 188.4 CSA Z460, S.7.4.2
Is there any specific training for the types of interventions or group of employees?	CSA Z460, S.7.5.2 (ROHS, art. 188.8)
What are the frequency and the reasons for retraining of personnel?	CSA Z460, S.7.5.2
Are the audits of procedures of alternative methods performed? By whom? For what reasons? At what frequency?	(ROHS, art. 188.5) CSA Z460, S.7.6.3
How do you proceed the audit/inspections? With what tools?	CSA Z460, S.7.6.3

5.3 Results and discussion

In this section, the state of the art and the issues observed in the actual practices of the application of alternative methods (against the requirements of the Canadian standard and Quebec regulation) are presented and discussed. The identified shortcomings and proposed recommendations for addressing them are also tabulated.

5.3.1 The concept of other methods of control of hazardous energies within the organizations studied

Only a few of the organizations (4/14) had technical knowledge about alternative methods. The understanding of alternative methods to control hazardous energies was challenging in most of the organizations visited. In general, there were no clear answers to the questions (e.g. What is an alternative method? When should they be used? By whom should they be used?). Interestingly, during each interview and after explaining of the concept of alternative methods, interviewees became more accustomed to the concept and, subsequently, examples of using alternative methods (e.g. electronically interlocked access or trapped key system) were found in each organization. In other words, the organizations used these methods without knowing that they were alternative methods as described in the regulation. Allen (2012) reported that one of the key shortcomings in understanding lockout/tagout is a lack of knowledge and failing to understand when lockout is required, and when safety devices and interlocks are suitable.

Only five organizations (including the four organizations which had technical knowledge of alternative methods) mentioned alternative methods in their lockout programs. In these programs, alternative methods were named: partial lockout, temporary lockout, special work permit, lockout for production tasks or lockout exemption. Moreover, the general procedure of using alternative methods was briefly explained and no lockout programs mentioned the risk analysis for alternative methods or a validation of the methods selected. The same result was found by Chinniah (2010) through a study on 31 lockout programs of different organizations. The author reported that only 14 programs referred to using alternative methods. In summary, we found that the use of alternative methods for the control of hazardous energies was not yet formally implemented in the organizations.

5.3.2 A general procedure for the application of alternative methods

Only six organizations had the procedures for the application of alternative methods (e.g. safety instructions, work permits). Nevertheless, in all of these procedures, some of the main elements/steps of the general procedure for alternative methods (article 188.5 of Quebec's ROHS) were missing. These organizations stated that a few of these steps were carried out in their procedures for the application of alternative methods. Table 5-4 shows the main elements/steps of the general procedure for alternative methods that were applied in these six organizations. For example, the table shows that only the first step (i.e. identification of the machine) was carried out in all the organizations (6/6) and was found in the procedures for alternative methods.

Table 5-4 The main elements/steps of the general procedure (for alternative methods) found in the organizations' general procedures.

Elements of a general procedure of alternative methods (ROHS, 2017)	**Found in the six organizations' general procedures**
Identification of the machine	6
Identification of the person responsible for the energy control method	5
Identification and location of every control device and of every energy source of the machine	0
Identification and location of every cut-off point of every energy source of the machine	1
The type and quantity of material required for applying the method	0
The steps required to control the energy	4
Where applicable, the measures designed to ensure the continuity of application of the energy control method during a staff rotation, in particular, the transfer of required material	1
Where applicable, the applicable characteristics, such as the release of residual or stored energy, the required personal protective equipment or any other complementary protection measure	4

Moreover, only two organizations reported that they used measures (e.g. a photo, pictogram, simplification) to facilitate an understanding of the procedures for the alternative methods. The use of pictograms to increase an understanding on the part of the workers about the warnings was recommended. We also found that procedures were available only in four organizations through the network and not posted at the workstation. Karimi et al. (2018) showed that difficulty in accessing some placards might explain why reading them was compromised. Furthermore, the application of alternative methods was recorded in only two organizations. In summary, the general procedure in most of the organizations visited was not in compliance with article 188.5 of

Quebec’s ROHS. Recommendations to address key shortcomings which are identified in this section are presented in Table 5-6.

5.3.3 Types of alternative methods used in the organizations

In this section and the following subsections, the alternative methods used in the 14 organizations are presented. Compliance with the Canadian standard and Quebec regulation are also evaluated and discussed. Tasks such as troubleshooting, unjamming and cleaning were the most frequent activities mentioned by organizations for using alternative methods to lockout. The first reason to use alternative methods was that tasks were integral to the production in 13 out of 14 organizations. In fact, it was mostly found in activities with the following characteristics: (i) short duration (11/14); (ii) relatively minor in nature (11/14); (iii) occurred frequently during a shift or production day (10/14); usually performed by operators, set-up persons, and maintenance personnel (10/14); and (iv) minimally interrupts the operation of the production process (8/14). The second reason (10 out of 14 organizations) was the need for equipment to be energized (e.g. the need for electrical energy).

Burlet-Vienney et al. (2017b) stated that prevalent alternative methods for lockout/tagout are electronically interlocked access, trapped key system, presence-sensing device or remote lockout. Studies showed that using an interlocked guard as alternative methods to lockout in cleaning and unjamming could not only be safe but, also could significantly reduce downtime (Main & Grund, 2017; Rasnic & Capps, 2004).

No remote lockout as an alternative method was found in the organizations studied. The alternative methods used by the organizations studied were categorized as follows: (i) control system – with the use of a personal padlock; (ii) specific control mode; (iii) temporary lockout / partial lockout; and (iv) permit, PPE and etc. At this point, it is of interest to note that all of these methods are procedural methods that require human action to be taken. The following sub-sections explained these categories with examples of the methods observed. These examples are summarized in Table 5-5.

Table 5-5 Other methods of controlling hazardous energies in the organizations studied

Type	**Examples of methods observed**	**Reason mentioned by the organizations**	**Number of the organizations**
Control system – with the use of a personal padlock	Moveable interlocked guards in an activated open position secured by a padlock	Continuity of production	10
	Safety devices (curtain, laser, camera, safety mats) locked in the activated position	Continuity of production	8
	Covers on control panels which are closed and locked	Continuity of production	1
	Teach pendants for robots (put them in a lockout box)	Continuity of production	1
	Trapped key devices	Both continuity of production and need for energy	2
	Emergency stop button with pad-lockable cap (in the activated position)	Continuity of production	1
Specific control mode	Control mode with reduced speed control (i.e. teach pendant for robots)	Continuity of production	2
Temporary lockout / Partial lockout	Partial energization or partial de-energization	Need for energy	2
Permit, safety instruction and PPE	Permit to enter the danger zone	Both continuity of production and need for energy	2
	Safety instruction/placard	Both continuity of production and need for energy	4

Table 5-5 Other methods of controlling hazardous energies in the organizations studied (cont.)

	Warning and alerting technique	Both continuity of production and need for energy	3
	PPE in working under voltage	Need for energy	7

5.3.3.1 Control system – with the use of a personal padlock

“Control system with the use of a personal padlock” was the most commonly encountered type of alternative method. Figure 5-1A-D illustrates some of the methods encountered. Figure 5-1A presents an emergency stop button with a pad-lockable cap as an alternative method in order to depress the button. Trapped key interlocking can provide acceptable protection as an alternative method to lockout as shown in Figure 5-1B. The method illustrated in Figure 5-1C included an interlocked guard in an activated open position secured by a padlock which was used to cut the power of one rolling machine and to not cut the power of all machines in the production line. A lockout box was also used (to put the padlock key on and allow the participants to put their padlock and their label). It may be somewhat complicated, but it shows that workers optimized the task as mentioned by Schuster (2016). Figure 5-1D shows another example of using safety devices locked in the activated position, by putting a piece of metal in front of the beam of the optical curtain and blocking it with a personal padlock. One organization stated that they sometimes used the emergency stop button as an alternative method to lockout.

According to ANSI/ASSE Z244.1 (2016), the level of safety for this type of alternative method must be firstly based on the reliability of safety-related control systems. The reliability of the control system must be evaluated when the risk reduction method is involved. The required level of reliability must be adapted to the level of risk of the hazardous situation (ANSI/ASSE Z244.1, 2016; ISO 13849-1, 2015). However, most of the organizations (12/14) reported that when the alternative method involved the control system, a validation of its reliability according to ISO 13849-1 (2015) was not carried out.

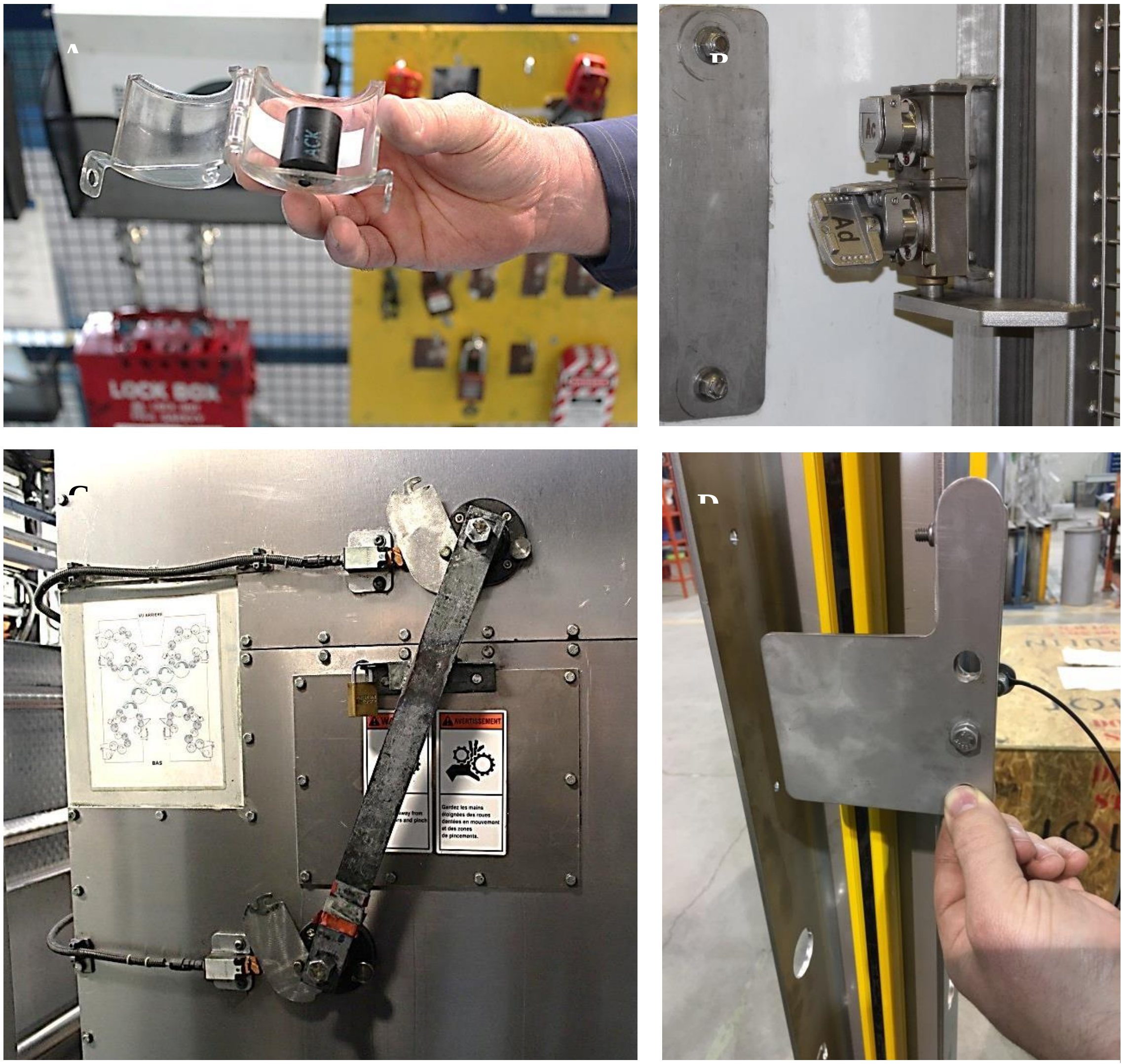

Figure 5-1: Control system – with the use of a padlock. A: Pad-lockable cap to emergency stop button; B: Trapped key system; C: Moveable interlocked guards in an activated open position secured by a padlock; D: Safety curtain that could be locked in the activated position

We also found different uses for the teach pendants for robots in three organizations. One organization used the teach pendant, with other control modes of the machine becoming inoperative, then engaged the emergency stop on the teach pendant, and finally put the pendant in a lockout box. Each worker who entered the danger zone put their own personal padlock on the box. On the other hand, the regular use of the teach pendant, which is a specific control mode, was found in two other organizations (i.e. a specific control mode whose engagement must cause all other control modes of the machine to become inoperative, reduce speed, control device requiring continuous action). The latter is detailed in the next sub-section.

5.3.3.2 Specific control mode

The Quebec regulation (art. 188.2 and 189.1) makes an unclear exclusion from lockout and also alternative methods where the machine is equipped with a specific control mode. This exclusion is not in accordance with the Canadian standard CSA Z460 (2013) and ISO 12100 (2010). Thus, in this paper, this exclusion was considered an alternative method to lockout. According to the regulation, work can be carried out in the danger zone of a machine with a specific control mode which allows the dangerous parts of the machine to be operated only (i) by using a control device requiring continuous action; or (ii) by using a two-hand control device; or (iii) by a continuous action of a validation device; or (iv) at reduced speed, under reduced tension, step-by-step; or (v) by means of a separate step control device. The latter needs a written procedure for each specific equipment/machine. This solution is appropriate when a need for movement and therefore energy is necessary for doing tasks; for example, troubleshooting, cleaning or adjustment.

The examples associated with the specific control mode were found in two organizations in which they used a control mode (e.g. teach pendant) with reduced speed control for robot cells or a bending machine. We also found that three organizations used the jog mode for the doing adjustment tasks (e.g. adjustment on a filler machine or cylinder alignment where the continuity of production is needed). Overall, we found that most of the organizations (11/14) had problems with understanding this approach. This proves that this article in the Quebec regulation needs to be revised in order to be precisely compliant with the CSA Z460 and ISO 12100 standards. Similar results were reported by Chinniah et al. (2017a) on the application of the Quebec regulation specifically article 189.1 at 15 machines in nine companies. The authors demonstrated that companies had difficulties in implementing this article owing to (i) some machines needed to be adapted on site based on the requirements of the article; (ii) workers who performed the tasks in the danger zone did not use a hold-to-run control or an inching/jogging advance mode; (iii) low level of workers' knowledge; (iv) the poor explanation of the article in the regulation; and (v) a lack of risk assessment. The authors also showed that the use of the reduced speed mode may not always be safe if the appropriate level of speed is not determined and the presence of other hazards is possible.

5.3.3.3 Temporary lockout / Partial lockout

Partial lockout, such as partial energization or partial de-energization, was used in two organizations. For example, in one organization a padlock (not the personal padlock) was used on the electrical disconnector during the cleaning of a wrapping machine in order to maintain the continuity of production (Figure 5-2). In fact, when the operator needed to enter the danger zone of the machine (e.g. moving a pallet), he placed the regular padlock available on the local disconnector of the machine and kept its key. However, there was no procedure, record, or register available for using this alternative method. The other organization used a plastic injection press with two disconnectors in order to keep energy on the extrusion system while working off energy in the mold zone.

Figure 5-2: Disconnector with a regular fixed padlock

5.3.3.4 Permit, safety instruction and PPE

In terms of the need for energy or the continuity of production, the organizations used other methods, including (i) permit to enter the danger zone (2/14); (ii) safety instruction, for example a placard for troubleshooting of a rolling machine (4/14); (iii) warnings, for example warning signs/tags (3/14); and (iv) PPE in working under voltage (7/14). According to National Fire Protection Association [NFPA] (NFPA 70E, 2015) and CSA Z462 (2015) standards, troubleshooting tasks on live voltage are accepted in some strict circumstances and if the worker uses proper PPE and proper tools. In one organization, for the under voltage intervention, a special work permit was used. This permit consisted of a checklist regarding electric shocks and arc flash hazards. It was filled out by a qualified worker. However, no risk analysis was found.

Moreover, Quebec's ROHS (art. 188.2) explains exclusions from lockout for specific equipment/machines where a machine has a single energy source or where there remains no residual energy after the machine is unplugged and is under the exclusive control of the person who uses it. Only three organizations had formal instructions for dealing with this exclusion, for example: through the alternative method placard (2) or by means of the permit to enter the danger zone [work permit] (1).

Main shortcomings of the alternative methods used, as discussed in the previous subsections, and recommendations for addressing them are summarized in Table 5-6.

Table 5-6 Shortcomings observed and possible improvements concerning the alternative methods used in the organizations

Standard and regulation on alternative methods to lockout	Actual practices	Recommendations and possible improvements
Minor tool changes, servicing activities and adjustments do not require lockout to be applied so long as they are "routine, repetitive, and integral to the use of the equipment" for production (CSA Z460, clause 7.4)	Organizations (10/14) had no technical knowledge about alternative methods. Alternative methods mentioned in only 5/14 lockout programs	Raise awareness of alternative methods by adding alternative methods in the lockout programs. Identify the tasks that can be exempted from lockout according to the standard or the situations in which application of traditional lockout is unnecessary
Main steps/elements in the general procedure for alternative methods in article 188.5 of Quebec's ROHS (See Table 5-4)	8/14 organizations had no procedure for alternative methods. Main steps of the general procedure of alternative methods were missing in the procedures used in the rest of organizations	Prepare the specific procedure for alternative methods which contains all the steps of the general procedure mentioned in the regulation. Add missing steps (as presented in Table 5-4) in the current procedures

Table 5-6 Shortcomings observed and possible improvements concerning the alternative methods used (cont.)

	Not mentioned in the programs	Add a general alternative procedure for alternative methods in the lockout program
Lockout exemptions on specific equipment/machines (ROHS art. 188.2 and 189.1). (As explained earlier in the subsection)	Little understanding of the regulation requirements (11/14)	Raise awareness of the ISO 12100 about reduced-speed or reduced-force work and also the regulation (ROHS art. 188.2, 189.1) through external for example, safety consultants
	No formal instructions in lockout programs	Add specific instructions in the program, including technical solutions for example, when using a specific control mode as an alternative method (operating machines equipped with a specific control mode at reduced speed, under reduced tension, step-by-step or by means of a separate step control device). Determination of the most appropriate values for reduced speed, force, pressure, and temperature. Share the document with internal and external workers (i.e. sub-contractors)

5.3.4 Risk assessment when using alternative methods to lockout

Quebec's ROHS (art. 188.4) requires employers who intend to apply an energy control method other than lockout, firstly ensure the equivalent safety of that method through a risk analysis. The results showed that the risk analysis was problematic for most of the organizations. For example, most of the alternative methods found in Table 5 were used without risk assessment. Almost two-thirds of the organizations (9/14) had problems with understanding this article. The organizations visited in which the program was not revised based on the current ROHS regulation or the CSA Z460 standard had more challenges with understanding and applying risk analysis for alternative methods. We found that only three organizations carried out a risk analysis to validate the use of alternative methods for a specific task (i.e. troubleshooting). It can be problematic as Lind (2008) showed that fatal accidents happen due to dangerous work methods that include risks. On the contrary, proper risk assessment has a good effect on the overall safety performance (Liu et al., 2014).

In that case, risk analysis was conducted by means of the risk matrix (2) and risk graph (1). The weaknesses of the risk matrix and recommendations for its improvement were studied by Cox Jr (2008), and Duijm (2015). The documentation of the risk assessment was neglected.

Four organizations stated that they applied a risk assessment for machine safety, but not specifically for alternative methods to lockout. However, one major difference between safety during production and maintenance is that the worker stays in the danger zone to do his job. Two organizations mentioned that they would carry out the risk analysis for alternative methods in the current year. Moreover, the risk assessment was not found for machine modifications and safeguards modified. These were the same results that Poisson and Chinniah (2016) reported. The authors found that in sawmills, permits were issued without a risk assessment as alternative methods for troubleshooting activities; this is an inappropriate approach that can result in serious injuries or death. Chinniah (2015) also showed that a lack of risk assessment or job hazard analysis aside from the other factors were the main causes of fatal accidents involving machinery.

In summary, whereas the use of alternative methods to lockout in the organizations studied was more prevalent, the actual practice was not in compliance with the Canadian standard and Quebec regulation, specifically risk analysis. In other words, risk assessment was problematic in the organizations visited. It would be likely a larger systematic issue than the application of alternative methods by itself. Key shortcomings and possible improvements and recommendations to address them are presented in Table 5-7.

Table 5-7 Shortcomings observed and possible improvements concerning alternative methods and risk assessment.

Standard and regulation on alternative methods to lockout	Actual practices	Recommendations and possible improvements
Ensure the equivalent safety method by analyzing the following (ROHS, art. 188.4):		
(1) The machine features; (2) Identifying risks when using the machine	- Application of alternative methods without risk assessment (11/14), in fact, they carried out the risk assessment only for a safe operation on machines. Use of a permit as alternative methods without risk analysis (3/14)	- Before the use of alternative methods or selecting the appropriate measure, risk assessment/ analysis is necessary and should be done by safety engineers. (Use alternative methods, only if the level of risk is acceptable). For example, when using control systems with the use of personal padlocks (as presented in Table 5) the validation of control system reliability (according to ISO13849) is necessary. Work permits (as mentioned in 3.3.4) without risk assessment must only be used during interventions supervised and authorized by the manager
(3) Risk estimation; (4) The estimate of the level of risk reduction and the assessment of residual risks	- Using inappropriate tools for risk estimation	- Use risk estimation tool such as matrices with well-defined parameters and thresholds, for example, three to five levels of the severity and probability and at least four levels of risk are recommended (Chinniah et al., 2011; ISO/TR 14121-2, 2012)
(5) Document the results of the analysis	- Lack of documentation of results of analyzing alternative methods to lockout (12/14)	- Document risk analysis results, share the documents with personnel and external contractors
	Not mentioned in the lockout programs (no formal instructions in programs)	Explain the process of risk analysis specifically for alternative methods in the lockout programs

5.3.5 Alternative methods and administrative factors

Training and auditing are important factors to ensure the optimal use of alternative methods. Both the Canadian standard and Quebec regulation require a specific training for employees who apply alternative methods and also implementing audit/periodic inspections of the application of alternative methods. In the following sub-sections, the training and audit were assessed against the Canadian standard and Quebec regulation expectations. More information about these factors (i.e. training and audit) in connection with the actual practice of lockout was studied elsewhere (Karimi et al., 2018).

5.3.5.1 Training

None of the organizations studied had a specific training/retraining program to ensure that authorized and affected individuals adequately understand the particular needs of a workplace in order to apply alternative methods (Quebec's ROHS, art. 188.8). According to CSA Z460 (2013), training on the use of other control methods must be a part of the training program on lockout. In other words, training must include samples of machine-specific procedures and enable personnel to interpret and implement procedures. Furthermore, periodic refresher trainings must be conducted at intervals not to exceed three years, to maintain an appropriate level of the worker's understanding. The content of this refresher training must be based on known hazards and risk assessment for the planned work activities and working conditions. The importance of the training assessment and retraining was reported by Demirkesen and Arditi (2015), and Kelley (2001). Taken together, the training for the use and application of alternative methods was not fully in compliance with the Canadian standard and Quebec regulation. Table 5-8 presents recommendations to address shortcomings in this area.

5.3.5.2 Audit/Inspections

According to the Canadian standard (CSA Z460, clause 7.6.3), annual auditing of written procedures and authorized personnel is necessary. Although eight organizations stated that they conducted audits for the application of lockout procedures, only two organizations performed audits or periodic inspections of the application of alternative methods through simple checklists. In fact, no appropriate tools for the audit of lockout and alternative methods were found. As mentioned earlier, most of the elements of a general procedure of alternative methods were missing in the organizations studied. Audits of the application of alternative methods help the organizations to identify these issues and to improve procedures for alternative methods. Taken together, audits were problematic in almost all of the organizations. Chinniah (2015) showed that a lack of audits of lockout procedures was one of the main causes of accidents related to machinery. Key shortcomings and recommendations for addressing them are presented in Table 5-8.

Table 5-8 Shortcomings observed and possible improvements concerning alternative methods and administrative factors (training/audits)

Standard and regulation on alternative methods to lockout	**Actual practices**	**Recommendations and possible improvements**
Require task-specific training (ROHS art. 188.8); Effective training (CSA Z460, clause 7.5.2): includes samples of machine-specific procedures and enable personnel to interpret and implement procedures	Lack of specific training in alternative methods to lockout	Conduct practical training at worksites and use more visual aids in theoretical training. For example, practical training for using a specific control mode as an alternative method according to ISO 12100 and the detailed approach is presented in Chinniah et al. (2017a)
	No formal instructions in lockout programs	Add specific training in the training program related to the application of different types of alternative methods (Table 5-5) for authorized/affected workers

Table 5-8 Shortcomings observed and possible improvements concerning alternative and administrative factors (cont.)

- The audit of alternative methods must be part of a lockout program (CSA Z460, clause 7.3.1). Annual auditing and documentation of audits (CSA Z460, clause 7.6.3; ROHS, art. 188.5)	- No specific audit of application of alternative methods for improving procedures, evaluating the performance of methods or finding problems (8/14 organizations)	- The audit must be conducted at least annually and documentation shall be maintained for at least three years. Periodic inspections of application of alternative methods, in particular, to update procedures of the application of alternative methods and every time a machine is altered or a failure is reported
	- Absence of appropriate audit tools	- Using a self-audit method, define valid questionnaires and checklists for alternative methods. For example, checklists regarding (i) the evaluation of the reliability of control systems when using a control system with the use of a personal padlock as an alternative method (presented in Table 5-5); or (ii) the assessment of the implementation of a specific control mode according to CSA Z460 and ISO 12100 standards' requirements
	- Lack of documentation of audit results (12/14)	- Document all the audit results and outcomes
	Not specifically mentioned in the lockout programs	Explain the audit process of alternative methods in the lockout programs

5.4 Conclusion

For the first time, a study on the application of alternative methods for the control of hazardous energy on machinery in different organizations was carried out. The purpose of the study was to understand the application of alternative methods to lockout and investigate how they were implemented in accordance with the Canadian standard and provincial regulation. In that regard, a questionnaire was prepared and the application of lockout and alternative methods in 14 organizations was analyzed through group interviews, document reviews and site observations. It was found that only a few of the organizations (4/14) had a proper understanding of alternative methods, while in practice, all of the organizations used other methods to lockout. However, we expected to find in-depth knowledge of alternative methods among organizations that used the Canadian standard or current regulation to develop their lockout program. Accordingly, the application of alternative methods was not fully compliant with the standard and the current regulation.

In summary, results indicated the need to increase knowledge about alternative methods to lockout and the regulation. Using alternative methods were prevalent among the organizations visited, whereas a risk assessment was not carried out before applying an alternative method. Moreover, a general working procedure for alternative methods was missing or incomplete in all the organizations. Poor training in alternative methods and lack of audit/inspections of their application were additional findings. In other words, the organizations studied were already using alternative methods without realizing that they were doing so and as such, the state of the art practices described in the standards and regulation were not in place. Hence, this study proposed recommendations to address the identified shortcomings and issues related to the application of alternative methods in the organizations studied.

Generally speaking, the emergence of cutting-edge technology in safety of machinery and also the organizations' tendencies to improve the safety and productivity may be the main reasons for using alternatives other than lockout. However, using them must be based on the results of risk assessment and always be in compliance with relevant standards and regulations. In spite of the fact that we found most of the organizations visited were using alternative methods, considerable efforts are needed to ensure that the use of these methods is optimal in terms of safety. The limits of alternative methods need to be understood. They must not be assumed to be easy options to bypass lockout. Risk assessment is necessary before using alternative methods in order to justify they can be used with equivalent safety. It also will enable residual energies that cannot be controlled only by using safeguards and protective devices to be identified. The reliability of interlocked safeguards is crucial if alternative methods rely on them to ensure the safety of workers. Such practices will ensure that organizations comply with standards and regulations. Risk assessment and the design of reliable safety-related parts of control systems should be targeted as a priority.

In the end, for future research, it would be valuable to research this topic in heavy industries (e.g. oil and gas or mining) or in different countries with various regulations and standards. Moreover, analysis of the accidents related to the control of hazardous energies in order to find the causes specifically linked to alternative methods and to understand the extent to which they are in connection with the shortcomings and gaps identified in this paper could be carried out.

Acknowledgements

The authors wish to thank the organizations that agreed to participate in this study and authorized the use of the photographs. Furthermore, the authors wish to thank the anonymous reviewers for their careful reading of this manuscript and their many insightful comments and suggestions. They also wish to thank the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), as well as NSERC for funding this research. This study was conducted as part of a project approved by the Polytechnique Montréal’s committee on the ethical conduct of research involving human subjects.

CHAPTER 6 ARTICLE 3: DESIGN OF A SELF-AUDIT TOOL FOR THE APPLICATION OF LOCKOUT ON MACHINERY IN THE PROVINCE OF QUEBEC, CANADA TO CONTROL HAZARDOUS ENERGIES

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This article was published in Safety 5.3 (2019): 53.

Abstract: Failure to apply lockout procedures for the control of hazardous energies is one of the main causes of machinery-related fatal and serious injuries in North America. The absence of audits of lockout or the lack of proper tools for auditing lockout is prevalent, and thus the application of lockout is often not fully in compliance with standards and regulations. A self-audit tool for the application of lockout procedures for machinery was developed on the basis of the current standards and regulations, and previous research. The tool was then tested for content validity through experts' opinions and qualitative feedback from six organizations in the province of Quebec in Canada. The developed audit tool defines the actual procedures to audit, as well as the surrounding conditions that are needed and the prerequisites based on standards, regulations, and findings from previous research. The results showed that the tool displayed a high content validity index and demonstrated that the applicability, and comprehensiveness of the tool were adequate. This self-audit tool helps organizations monitor the application of lockout on machinery for the safety of workers and to ensure that the actual practice of controlling hazardous energy is in compliance with relevant standards and regulations.

Keywords: self-audit tool; lockout procedure; application of lockout; content validity; safety of machinery

6.1 Introduction

6.1.1 Safety audit

The international standard ISO 19011 explains that an audit is a systematic, independent and documented process to obtain objective evidence and evaluate it objectively to determine the extent to which the audit criteria are being fulfilled (ISO 19011, 2018). The audit can also be internal or external. The standard states that internal audits are conducted by, or on behalf of, the organization itself. On the other hand, external audits are conducted by other individuals outside of the organization or by independent auditing organizations [e.g. governmental agencies] (ISO 19011, 2018). The internal audit allows the organization to determine if its occupational health and safety (OHS) management system is effectively implemented and maintained, and also whether it is compliant with standards (ISO 45001, 2018; CSA Z1000, 2014). A safety audit can be based on regulatory or other compliance assessments (i.e. compliance-type audits) through a review of the documents, interviews and observations to determine whether the workplace is safe (Esposito, 2009; ISO 19011, 2018). Occupational Safety and Health Administration (OSHA) recommends regular workplace inspection and compliance audits and mentions self-assessment auditing as an effective method to evaluate and improve safety programs (OSHA, 1999). In spite of this fact, conducting internal audits is less widespread in small companies (Grant & Brown, 2005; Parker et al., 2015b), which prefer performing external audits likely because of a shortage of qualified internal auditors or resources (Birkmire et al., 2007).

Checklists and questionnaires are prevalent tools/methods for auditing safety management systems (Kuusisto, 2000). Checklists are helpful to conduct observational audits (Gray et al., 2016). Depending on the objectives of the audits of an OHS management system (Blewett & O’Keeffe, 2011), it is important to assess measurement properties (e.g. validity, reliability) of the audit tool and to find the extent to which they are acceptable (Huang & Brubaker, 2006; Robson & Bigelow, 2010). These authors showed, for example, that the content validity of an audit instrument is the most important test before auditing every OHS management system. Content validity indicates the comprehensiveness of the audit tool and the extent to which it represents OHS system concepts (Terwee et al., 2007). On the other hand, assessing inter-auditor reliability or the responsiveness of a tool is more important when the measurement of the performance of a safety system is the main objective of an audit (Robson & Bigelow, 2010).

6.1.2 Audit of lockout

North American standards and regulations address the minimum requirements necessary for the methods which are carried out during the non-production phase (e.g. service, repair, and maintenance) of machinery to control hazardous energies [e.g. electrical, hydraulic, pneumatic, kinetic, potential, chemical, and thermal in nature] (ANSI/ASSE Z244.1, 2016; CSA Z460, 2013). These standards and regulations require a specific lockout procedure for each machine, equipment or process in accordance with the general lockout procedure. The general lockout procedure provides authorized employees with a step-by-step approach to controlling hazardous energies, and requires: (i) preparation for shutdown; (ii) shutdown of machine, equipment or process; (iii) isolating machine, equipment or process isolation; (iv) application of lockout devices; (v) dissipating and controlling stored energy (de-energization); and (vi) verification of isolation (Chinniah & Burlet-Vienney, 2013; CSA Z460, 2013; Poisson & Chinniah, 2016; ROHS, 2017). Moreover, some standards and regulations require a documented lockout program that establishes the company's general policies and procedures for implementing lockout (ANSI/ASSE Z244.1, 2016; CSA Z460, 2013). Lockout programs should comprise the following elements: (i) identification of the hazardous energy covered by the program; (ii) identification of the types of energy isolating devices, (iii) identification of the types of de-energizing devices; (iv) selection and providing of protective devices and hardware; (v) assignment of roles and responsibilities; (vi) the general lockout procedure; (vii) alternative methods; (viii) training; and (ix) audit and inspections (Burlet-Vienney et al., 2009; Chinniah, 2010; ANSI/ASSE Z244.1, 2016; CSA Z460, 2013; Poisson & Chinniah, 2015; ROHS, 2017). The Canadian standard CSA Z460 (2013) and American standard ANSI/ASSE Z244.1 (2016) state that compliance with specific hazardous energy control procedures (machine, equipment, or process) is critical. These standards (CSA Z460, clause 7.6.3; ANSI/ASSE Z244.1 clause 6.5.2) require companies to "establish a continual auditing plan (at least annually) that will provide current information on the maintenance of application effectiveness. The application effectiveness audits should be random and address all shifts, days of operation, groups, non-standard work situations and personnel". Knowledgeable personnel should conduct visual observations of authorized individuals performing specific hazardous energy control tasks. These observations should include feedback to the authorized individuals and documentation of the findings and any recommended improvements" (ANSI/ASSE Z244.1, 2016; CSA Z460, 2013). Furthermore, audit results can reveal the need for retraining. The audit must be a part of the lockout program in which the frequency of the audit, sample size, auditor's responsibilities and documentation of an audit are explained (ANSI/ASSE Z244.1, 2016; CSA Z460, 2013). In Quebec, the regulation ROHS (2017), which is almost in line with North American standards and OSHA 29 CFR 1910.147, requires that employers revise the lockout procedures periodically. However, the audit of the lockout program is not mentioned in the regulation. Similarly, OSHA 29 CFR 1910.147 (1989) requires that the employer conduct periodic inspections of lockout/tagout procedures at least annually to ensure that the procedure and the requirements are being followed, and also to correct any deviations or inadequacies identified. However, by contrast to OSHA 29 CFR 1910.147, the Quebec regulation (ROHS) requires that tagout be only utilized as an alternative method to control hazardous energy. According to OSHA 29 CFR 1910.147, the periodic inspection must be a part of the lockout program. The regulation [1910.147(c)(7)(iii)(B)] also explains that "additional retraining shall also be conducted whenever a periodic inspection reveals, there are deviations from or inadequacies in the employee's knowledge or use of the energy control procedures" (OSHA 29 CFR 1910.147, 1989). Auditing is imperative in both these regulations. The requirements for auditing lockout in North America are briefly described in Table 6-1. This table includes requirements from the Canadian and American standards on lockout, OSHA 29 CFR 1910.147, and Quebec's regulation.

As Table 6-1 demonstrates, the audit of the application of lockout should at least consist of the verification of lockout procedures and the observation of the application of lockout, which is carried out by authorized employees.

Table 6-1 Audits of lockout in North American standards and regulations

Standard/regulation	Audit of a lockout program (i.e. elements of a program)	Audit of the application of lockout procedures
CSA Z460	Auditing of program elements (lockout program review). This monitoring and measuring frequency shall be at regular intervals of three years or less.	The user shall be responsible for conducting the auditing plan (e.g. semi-annually) through visual observations of authorized individuals applying specific lockout procedures to verify that complete compliance is occurring.
ANSI/ASSE Z244.1	Auditing of program elements (lockout program review). This monitoring and measuring frequency shall be at regular intervals of three years or less.	The user shall be responsible for conducting the auditing plan (e.g. semi-annually) through visual observations of authorized individuals applying specific lockout procedures to verify that complete compliance is occurring.
Quebec's ROHS (art. 188.5)	Not mentioned in the regulation	"The procedures must be reviewed periodically, in particular every time a machine is altered or a failure is reported, so as to ensure that the energy control method remains efficient and safe."
OSHA 29 CFR 1910.147 [1910.147(c)(6)(i)(A); 1910.147(c)(6)(i)(C)]	Not mentioned in the regulation	"The periodic inspection shall be performed by an authorized employee other than the ones(s) utilizing the energy control procedure being inspected. It must include a review, between the inspector and each authorized employee, of that employee's responsibilities under the energy control procedure being inspected."

6.1.3 Deficiencies related to the audit and application of lockout

The U.S. Bureau of Labor Statistics (BLS) revealed that in the period 2015-2018, a total of 723 fatal work injuries annually (approximately 14% of total fatalities) occurred as a result of contact with objects and equipment (BLS, 2018). Moreover, OSHA reported that lockout was the fifth most cited OSHA violation in the period 2015-2018. For example, during 2017 and 2018, OSHA issued 3,131 and 2,944 citations, respectively, for violations of the lockout/tagout standard OSHA 29 CFR 1910.147. The lack of documented lockout procedures and the absence of periodical inspections were two of the most-cited sections in the lockout/tagout standard (OSHA, 2017; OSHA, 2018). Likewise, in the province of Quebec (Canada) on average, 10% of fatalities occurred annually due to poor or absent lockout procedures (CNESST, 2016). Studies showed that one of the leading causes of lockout-related accidents in North America was the absence of lockout procedures (Bulzacchelli et al., 2008; Chinniah, 2015; Ruff et al., 2011). Chinniah (2015) indicated that relying on the lockout program as a measure of actual lockout practices was not a reliable factor since accidents happened due to failure in the application of lockout procedures in organizations that even have lockout programs.

Several studies have explained the importance of audits on lockout. Kelley (2001) indicated that periodic inspections of the application of lockout procedures make it possible to correct observed deficiencies. The auditor must observe a sufficient number of authorized personnel who apply a lockout procedure. The author explained that the audit of the application of a lockout procedure should address the following three main questions: (i) are the steps of the lockout procedure being followed correctly?; (ii) do authorized employees understand their responsibilities for lockout?; and (iii) is the lockout procedure adequate to control the energy? For each question, if the answer is negative, the auditor must describe the problem and the corrective measures taken or that are planned. Grund (1995) stated that audits allow companies to evaluate actual practices of implementation of lockout and to identify the problems (linked to the adequacy and efficiency of lockout procedures and also employee training) and to correct them. The author recommended that the audit should cover five aspects, including (i) machinery; (ii) lockout procedures; (iii) alternative methods, (iv) training; and (v) worker perception. The worker perception of lockout was discussed through situation awareness [SA] (Illankoon et al., 2019).

Karimi et al. (2018) investigated the actual practice of controlling hazardous energies in deferent organizations and demonstrated several major shortcomings to the control of hazardous energies on machinery, such as missing steps in lockout procedures, neglecting to read the placards before applying lockout, and not having appropriate audit tools or the absence of audits. Their findings were consistent with another study reporting the problems such as (i) the lack of audits; (ii) not always using lockout placard; and (iii) not performing the verification step of lockout procedures during the application of lockout (Poisson & Chinniah, 2016). Furthermore, Karimi et al. (2018) showed that although organizations conduct internal audits on lockout (e.g. auditing their lockout program or auditing the application of lockout), lockout audits are incomplete due to a lack of appropriate audit tools. To illustrate, they found that 40% of the organizations they studied had no tools for audits of lockout and existing audit tools (of the remainder of the organizations) consisted of only a few questions to verify the application of lockout, thereby deficient in completeness. Additionally, in some of the organizations, the audit of lockout was a small part of general safety audits, and it was incomplete. The authors concluded there is a need for a comprehensive tool for internal audits of lockout to provide organizations with accurate audit results (Karimi et al., 2018).

To our knowledge, the study of developing a valid and complete self-audit tool for the application of lockout on machinery is new. There are no proposed audit tools in the standards or regulations. Yamin et al. (2017) introduced a self-audit tool (checklist) for lockout in manufacturing workplaces. Whereas their tool showed good inter-rater reliability, the content of the tool does not encompass all of the requirements of the application of lockout procedures carried out by authorized employees. For example, questions (items) on continuity of lockout, external services and assessment of some steps in a general lockout procedure could be included in their tool.

In the present study, the main objective is to develop a valid and proper self- audit tool specifically for the application of lockout procedures on machinery. A tool for the audit of a lockout program already exists (Burlet-Vienney et al., 2009). Our novel tool defines the actual procedures to audit, as well as the surrounding conditions that are needed and the prerequisites based on standards, regulations, and findings from previous research. It consists of pre-audit and audit and stages that are absent in existing tools. The new tool is complete, easy to use, serves as a checklist and is practical in order to help organizations conduct internal audits of the application of lockout for controlling hazardous energies.

6.2 Materials and Methods

6.2.1 Developing the self-audit tool

A self-audit tool was developed by the research team on the basis of the findings of Karimi et al. (2018) (i.e. major shortcomings in the control of hazardous energies on machinery), the current standards (ANSI/ASSE Z244.1, 2016; CSA Z460, 2013) and regulation (ROHS, 2017), and a review of the literature. Indeed, the checklist statements were mostly designed based on our prior study (i.e. shortcomings in in the control of hazardous energies on machinery, related recommendations, and the questionnaire used) (Karimi et al., 2018) and the requirements for the application and audit of lockout procedures from: (i) the American standard ANSI/ASSE Z244.1 (e.g. clauses 6.5.2, 7.2, and 7.6.10-11), (ii) the Canadian standard CSA Z460 (e.g. clauses 7.6.3, 7.3.2.3 – 7), and (iii) Quebec regulation ROHS (arts. 188.5-8, 188.10 -11). The final self-audit tool is presented in Section 3 (Results).

According to the literature, lockout is applied by authorized employees through lockout procedures. Therefore, before the observation of the application of lockout, which is carried out by authorized employees, it is necessary to verify the availability and content of lockout procedures, the availability and condition of lockout materials/hardware, and the training records of authorized employees (using audit records can be useful as well). This verification is important for finding gaps or deficiencies and for correcting them before the evaluation of the application of lockout. Thus, in this paper, the self-audit tool for the application of lockout consisted of the two stages, (i) the pre-audit and (ii) the audit. These two stages of the tool comprised a set of checklist statements that were in fact the pre-requirements and requirements of the application of lockout procedures. For each statement, if the pre-requirement or requirements were met, they could be marked with a check (✔); if not, they could be marked with an x (X), and if not applicable, they could be marked (N/A). The latter was clarified in related checklist statements. In the pre-audit stage, if each checklist statement was not met, required actions would need to be taken by auditors or organizations. In this regard, the required actions were defined and embedded in the pre-audit stage (on the tool) to help organizations address problems. In the audit stage, the auditors could write their comments in the designated column of the tool. The tool also consisted of general instructions and general information (Table 6-2).

Table 6-2 Self-audit tool: Instructions and General information

Instructions
This self-audit tool has been developed for the application of lockout. By using the self-audit tool, organizations can evaluate the application of lockout carried out by an authorized employee or an external contractor. The audit should be performed by internal auditors who are experts in lockout. Before performing the audit, the auditors must read these instructions as well as the guidelines provided in the tool. The tool is considered generic as it includes recommendations from the standards CSA Z460 (2013), ANSI/ASSE Z244.1 (2016) and Quebec regulation ROHS (2017).   The audits can be random or planned and can address all shifts, days of operation, groups, non-standard work situations, and individual personnel. Organizations can determine the frequency of monitoring and sample size. Detailed information about audit schedule/planning and documentation usually can be found in lockout programs.   • ***The tool and process of self-audit***   This tool is a comprehensive checklist based on a self-audit process and explains how to carry out the audit of the

Table 6-2 Self-audit tool: Instructions and General information (cont.)

application of the lockout. The self-audit process consists of the two stages named pre-audit and aud it. Before starting, the auditor must select in advance a machine/equipment and/or a task for which lockout is applied. Pre-audit: consists of 4 sections (general conditions, content of the procedure, authorized employee, and required lockout hardware). In this stage, the auditor must ensure that the necessary conditions/ pre-requirements are met. First, the physical conditions are checked (e.g. existing and up-to-date lockout procedure, available lockout material, adequate and functional energy isolation devices). The auditor then verifies training records of authorized employees and also previous audit/inspection records. The tool provides the required actions linked to the pre-requirements which are not met. If pre-requirements are not met, the organization needs to take action to correct them. In this regards, the lockout program also needs to be verified. The verification of lockout program elements (e.g. general lockout procedure, training, audit, subcontractors) is available on the website of the IRSST (i.e. verifying the content of lockout programs: RF-635). Audit: consists of 2 sections (de-energizing steps and re-energizing steps). In this stage, the auditor, along with the previously-checked lockout procedure, observes the actual application of lockout for the targeted equipment or task and checks each requirement thereof in the tool through his/her observation and verified lockout procedure (i.e. the lockout procedure has been checked in the previous stage). The auditor can write his/her notes or comments (in the right column) for each requirement which is not met.
General information
Name of department/section:
Machine, process, or equipment being observed: Task being observed:
Employee(s) being observed: ☐ Authorized employee(s) ☐ External services (sub-contractor):
Name/title of auditor: ☐ Owner or general manager ☐ Safety director/supervisor ☐ Shop supervisor ☐ An authorized employee other than the one(s) working on this machine, process, or equipment
Signature: -------------------------- Date of pre-audit: ------------ / ------------ / ----------- Date of audit of the application: ------------- / ------------- / ----------

6.2.2 Validation and analysis of the tool

After developing the self-audit tool, the tool was evaluated for content validity to ensure that all of the requirements of the standards (i.e. CSA Z460 and ANSI/ASSE Z244.1) and Quebec regulation (ROHS) are fully reflected in the tool. The assessment was a two-step process, including a review by a panel of experts and testing by the six recruited organizations in the province of Quebec (Canada). The expert panel in this study comprised six experts in the control of hazardous energy who were the representatives of different sectors including: (i) governmental sector on standard and regulation (i.e. CNESST: Commission des normes, de l'équité, de la santé et de la sécurité du travail); (ii) equipment and machinery fabrication; (iii) pulp and printing industry; (iv) transport and warehousing; (v) hospital sector; and (vi) manufacturing sector.

Before assessing the tool for content validity, it (the content of the tool) was translated from English into French, since the official language in the province of Quebec (Canada) is French. In the first step, the tool was presented to an expert panel in a group meeting. The experts were asked to judge the appropriateness and relevance of the checklist statements of the tool and the extent to which they agree with them (a scale ranging from irrelevant to highly relevant). All feedback was collected and then the content validity index (CVI) was assessed through (i) calculation of the content validity index for items (I-CVI), which is computed for each item (i.e. statement) as the number of experts find it relevant or highly relevant, divided by the total number of experts (Lynn, 1986); (ii) calculation of the content validity index for scale (S-CVI), which is computed as the average of the I-CVIs for all items on the scale (i.e. all of the statements in the tool) by adding up the I-CVIs, then dividing them by the total number of items (Waltz et al., 2005).

Subsequently, in the next step, the self-audit tool was tested by six organizations in order to receive their feedback (including more practical points of view) after using this tool for the application of lockout procedures. The research team also sent a short questionnaire about the content, usability, and completeness of the tool (Table 6-3). The organizations could contact the research team (through phone or email) in case they had questions about the tool. The feedback received from each organization were categorized by tabs in a Microsoft Excel© file to facilitate qualitative data analysis (Meyer and Avery, 2009). Each tab corresponds to the aspects of the questionnaire listed in Table 6-3. Each tab includes a number of columns based on the questions and also six rows assigned to the organizations selected. All the feedback of each organization was entered in the related cells.

Table 6-3 Questions used for testing content validity.

Aspect (Elements considered)	Questions for participants involved in testing the tool
Content of the tool	Are the statements clear and understandable? Does the sequence of statements make sense? Is the tool in line with the lockout regulation? To what extent?
Usability of the tool	Is it easy to use the tool? To what extent? Does it meet your expectations? Does the tool meet your needs?
Comprehensiveness and completeness of the tool	Is the tool complete and covers all points for an audit of the application? Is there any statement that needs to be added or completed?

6.2.3 Organization recruitment

For the present study, six organizations in the province of Quebec (Canada) were selected and recruited on the basis of convenience sampling (Bricki & Green, 2007; Patton, 2002). However, the organizations recruited were diverse in terms of industry, size, and machinery/equipment (as a heterogeneous group of organizations). Table 6-4 summarizes the list of organizations that were selected. Having at least five years of experience (the main selection criterion) with lockout on machinery was mandatory for the organizations selected. As shown in Table 6-4, all organizations selected had some experience with internal audits on the application of lockout. However, this was not a criterion for selection.

Table 6-4 General information about the six organizations in the study

Organization	Sector	Size (Number of employees: <100; <500; ≥500)	Number of items of machinery/equipment (approximately)	Existence of a safety committee	Experience about audits of lockout
A	Chemical industry	<100	125	Yes	Yes
B	Manufacturing	<500	800	Yes	Yes
C	Printing	<500	100	Yes	Yes

Table 6-4 General information about the six organizations in the study (cont.)

Organization	Sector	Size (Number of employees: <100; <500; ≥500)	Number of items of machinery/equipment (approximately)	Existence of a safety committee	Experience about audits of lockout
D	Municipal	≥500	5000	Yes	Yes
E	Pulp and Paper	<500	4000	Yes	Yes
F	Aerospace	≥500	1300	Yes	Yes

6.3 Results

6.3.1 Self-audit tool for the application of lockout

The validated self-audit tool is presented in Table 6-5 and Table 6-6, which are the pre-audit and audit stages respectively. A brief guide at the beginning of each table is provided.

The pre-audit (stage) of the application of lockout (Table 6-5) comprises four sections:

(i) General conditions: three statements indicate and check the pre-requirements linked to the existence of a written and updated lockout procedure and the characteristics of the equipment selected.

(ii) Content of the lockout procedure: 12 statements present and verify the pre-requirements ensuring completeness of the content of the procedure.

(iii) Authorized employee/ Sub-contractor: two statements indicate and review the pre-requirements linked to the training/retraining records of the related authorized employees as well as the existence of an authorization permit for external services (if applicable).

(iv) Required lockout hardware/material: three statements indicate and check for the pre-requirements linked to the availability of required lockout hardware in the application of lockout.

The audit (stage) of the application of lockout (Table 6-6) consists of two sections:

(i) De-energizing steps: 16 statements represent and verified the requirements linked to the de-energizing equipment/machine step.

(ii) Re-energizing step: eight statements represent and verify the requirements linked to the step on returning to service or re-energizing equipment/machines.

Table 6-5 Self-audit tool: Pre-audit of the application of lockout

Pre-audit of the application of lockout		
<u>Guidelines</u>: Before performing the audit of the application of lockout on the selected equipment/task, it is necessary to check the pre-requirements mentioned below. Read the requirements carefully. Mark (✔) if a requirement is met; (**X**) if not met; (N/A) if not applicable. If lockout is applied by external services/subcontractor, in each statement, “authorized employee” should be replaced with “external services”.		
Pre- requirements (of pre-audit**)**	**✔ X N/A**	**Required Actions (if the pre-requirement is not met)**
General conditions		
The equipment/machine/process has a written lockout procedure for the targeted task		Written lockout procedure must be provided and tested (exception: where a machine is unplugged under the exclusive control of the person who uses it, or where the machine has a single energy source and where there remains no residual energy after the machine is unplugged). The audit should be postponed until a written lockout procedure is provided
The procedure has been updated or modified based on recent changes in the selected machine/equipment/process		If there have been changes in the machinery or tasks, the procedure must be updated and verified. The date of creation, revision, and update of each lockout procedure must be documented
The equipment/machine is in good condition (operating status, energy cut-off points, control system, guards and safeguards, etc.)		A visual check is necessary to check the general conditions of the equipment. Safety aspects are covered at this point
The content of the lockout procedure		
Identification of the equipment/machine		The missing item must be added to the lockout procedure. ANSI/ASSE Z244.1:16 (7.2.1), CSA Z460-13 (7.3.2.4) and the Quebec regulation (sections 188.6 and 188.7) describe the minimum content of a
Identification and location of every control device and every energy source of the equipment/machine		

Table 6-5 Self-audit tool: Pre-audit of the application of lockout (cont.)

Identification and location of every cut-off point of every energy source of the equipment/machine		hazardous energy control procedure
Identification of the person responsible for the lockout procedure		
The type and quantity of material required for applying lockout		
Procedural steps for the application of lockout:		
• deactivation and complete shutdown of the equipment/machine;		
• elimination or, if that is impossible, control of any residual or stored energy source;		
• lockout of the equipment/machine's energy source cut-off points;		
• verification of lockout by using one or more techniques making it possible to reach the highest level of efficiency;		
• safely unlocking and re-operating the equipment/machine		
Where appropriate, the required personal protective equipment or any other complementary protection measure		
Where appropriate, identification of the transfer of responsibilities or required material to ensure the continuity of lockout during a staff rotation/shift change		
Authorized employee/subcontractor		
Each authorized employee(s) (who will be audited) has been trained or retrained if needed		Check the training/retraining records specifically if there is a change in the machinery or tasks. In general, retraining must not exceed three years, otherwise provide training and document the records. Training requirements are explained in the lockout program
In the case of the external services/sub-contractor, a		The written authorization for external services must be

Table 6-5 Self-audit tool: Pre-audit of the application of lockout (cont.)

written authorization has been issued for the external services/sub-contractor before undertaking work in the danger zone		provided before the application of lockout. The lockout program provides more detail on the management of external services
Required lockout hardware or devices		
Appropriate lockout devices/hardware for each type of energy control point of the equipment/machine are available and easily accessible in a lockout station or next to machinery		Visual inspection is required to verify the availability and accessibility of required equipment
The material required for the application of the procedure is in good condition *(Statement was added after re-analysis of the organizations' feedback)*		A visual check is necessary to check the condition of the equipment
The lockout station is generally in good order (e.g. cleanliness, presence of equipment other than that required for the targeted procedure) *(Statement was added after re-analysis of the organizations' feedback)*		

Table 6-6 Self-audit tool: Audit of the application of lockout

Audit of the application of lockout
<u>Guidelines</u>: The auditor, along with the previously-checked lockout procedure, observes the application of lockout carried out by the authorized employee(s) or external services (sub-contractors). The auditor can identify gaps quickly by using the tool and the lockout procedure (which has been checked in the pre-audit stage) when observing the authorized employee(s). The actual practice of the application of lockout procedure, including the de-energizing steps, placing lockout hardware and energizing (re-energizing) steps, is observed. Read the requirements carefully. Mark (✔) if a requirement is met; (**X**) if not met; (N/A) if not applicable. If lockout is applied by external services/ subcontractors, in each statement, "authorized employee" should be replaced with "external services".

Table 6-6 Self-audit tool: Audit of the application of lockout (cont.)

	Requirements (of audit**)**	✔ **X N/A**	**Auditor's note**
De-energizing steps			
1	The lockout procedure is easily accessible to the authorized employee (e.g. posted near the equipment, available on the intranet)		
2	Authorized employees search for the lockout procedure and read its contents		
3	Authorized employees get appropriate lockout equipment and devices (e.g. lockout box, padlocks, hasps) *(Statement was moved from pre-audit stage after re-analysis of the experts' feedback)*		
4	Affected employees are notified before applying the lockout procedure		
5	The authorized employees identify all hazardous energy sources of the equipment/ machine to be locked out (as per the procedure)		
6	The authorized employees mark off the places (e.g. using warnings and signs) where work is carried out in order to protect any employee who is likely to be exposed to danger *(Statement was added after re-analysis of the experts' feedback)*		
7	The equipment/machine is shut down by using normal stopping procedures (e.g., putting a switch in the "off" position)		
8	The equipment/machine is isolated from every energy source (e.g., close valves, switch off main disconnects, switch off circuit breakers)		
9	The authorized employees apply hasps and their personal padlocks and information tags in accordance with the lockout procedure		
10	The type of lockout required (e.g. simple or group) is respected as per the procedure *(Statement was added after re-analysis of the organizations' feedback)*		
11	All potential residual hazardous energies are relieved, disconnected, or restrained (e.g., the hydraulic or pneumatic system purged, trapped pressure relieved, pipe flanges blanked, elevated equipment blocked or supported)		
12	The verification step (verification of isolation) is performed according to the established procedure to ensure that the equipment/machine cannot be operated (e.g., push start buttons, turn on disconnects, test circuitry, measure the voltage or hydraulic		

Table 6-6 Self-audit tool: Audit of the application of lockout (cont.)

	pressure, visual inspection of measuring instruments by authorized employees or supervisors)		
13	In the case of more than one authorized employee working on equipment, all employees affix their own (personal) padlocks according to the established procedure		
14	In the event of several authorized employees working on the equipment, all employees have the opportunity to participate in the verification step according to the established procedure *(Statement was added after re-analysis of the organizations' feedback)*		
15	In the case of personnel or shift change, the authorized employee follows the instruction to ensure the continuity of lockout, as mentioned in the procedure		
16	In the event that a change in the type of lockout is required, authorized employees follow the instructions, which are explained in the lockout program *(Statement was added after re-analysis of the organizations' feedback)*		
Re-energizing steps			
17	Before lockout removal, authorized employees verify that the affected employees are safe and away from the equipment		
18	The equipment/machine is inspected to ensure that it is ready to return to service. All equipment components are intact and capable of operating properly (e.g., machine guards are in place, etc.) *(Statement was added after re-analysis of experts' feedback)*		
19	Padlocks are only removed by the authorized employees who applied them		
20	In the case of the absence of an authorized employee, the supervisor or employer follows the instructions for removing the padlock(s) of the absent authorized employee *(Statement was added after re-analysis of the organizations' feedback)*		
21	The equipment/machine is resupplied according to the established procedure		
22	The authorized employees start the equipment and check that everything is working properly and that the work is finished (e.g. ensure that all work and interventions are completed)		

Table 6-6 Self-audit tool: Audit of the application of lockout (cont.)

23	All affected employees are notified of the completion of the intervention		
24	The application of the procedure is recorded according to the established procedure (e.g., by archiving or by filing a register, etc.)		
Other comments/problems observed (including comments from authorized employees**):**			

6.3.2 Content validity

The feedback from the six experts in the group meeting demonstrated that they recognized all checklist statements as relevant items, a sign that the experts had reached a consensus. The calculated CVI (content validity index) for each checklist statement and the entire audit tool revealed a high validity rate. In other words, for the pre-audit checklist (Table 6-5), all of the statements except one had the highest CVI scores (I-CVI=1). The experts (3/6) found one statement (about getting appropriate lockout equipment and devices) to be an irrelevant statement (I-CVI= 0.5) in the pre-audit stage and proposed moving it to the audit stage (Statement 3 in Table 6-6). The content validity index for the scale also had a high score (S-CVI= 0.972). Similarly, all checklist statements in the audit stage (Table 6-6) were found to be relevant or highly relevant, and therefore the CVI score for each statement was 1, and content validity index for the audit checklist had the highest score (S-CVI= 1). The details of the calculation of I-CVI and S-CVI for the tool (pre-audit and audit checklists) are presented in Appendix C. Furthermore, the experts proposed that two items needed to be added to the audit stage: (i) statement 6 (about marking off the places (e.g. using warnings and signs) the places where work is carried out) in the de-energizing steps, and (ii) statement 18 (which is about inspecting the equipment/machine to ensure that it is ready to return to service) in the re-energizing steps, as shown in Table 6-6. Moreover, all of the experts (6/6) also found the tool to be clear and understandable.

After this first step of validation, the six organizations (shown in Table 6-4) tested the tool on actual lockout practices. Half of the organizations reported that they tested the tool on several equipment/machines. One organization tested the tool on the equipment when using group lockout. The qualitative feedback was analyzed and categorized in terms of the content, the usability, applicability, completeness, and comprehensiveness of the self-audit tool. The content of the entire tool was clear and understandable to all of the organizations (6/6). All the six organizations found that the tool was easy to use and applicable. Four organizations (4/6) proposed adding several items to the tool. Table 6-7 shows the main feedback collected from the organizations and the modifications required to address that feedback in the tool. In addition, according to the main feedback/comments, the required changes were made and the tool was updated (as shown in Table 6-5 and Table 6-6). Furthermore, since all the organizations (6/6) stated some experience with internal audits of lockout, they were asked to send their available audit tools. Four audit tools for the application of lockout were collected and analyzed by the research team. It was found that their tools were very simple (i.e. only a few questions were used to verify the application of lockout) and were not even in accordance with the Canadian standard and Quebec regulation.

Table 6-7 Main feedback and comments by the organizations on the self-audit tool in terms of content validity and required modifications to the tool.

Aspect	**Feedback and comment**	**Required modifications to the tool**
The content of the tool	One organization proposed for more examples to be provided for statements 11, 12, and 24	Notable examples were added to the related statements
The usability of the tool	No critical comments/ feedback	No action needed
The comprehensiveness and completeness of the tool	Several items needed to be added to the tool: - In the pre-audit stage: (i) the integrity of the equipment (the lockout equipment and energy cut-off points are in good condition); (ii) the lockout station is in good order (cleanliness and presence of equipment) - In the de-energizing steps of the audit: appropriate steps to verify when applying a group lockout - In re-energizing steps of the audit: appropriate steps to verify when the equipment requires padlock removal and re-operation	- Two checklist statements were added in the section “Required lockout hardware/ material” of the pre-audit - Statements 10, 14 and 16 were added in the de-energizing steps of the audit - Statement 20 was added in the re-energizing steps of the audit

6.4 Discussion

In this study, to develop the self-audit tool for the application of lockout, all the requirements of the relevant standards (ANSI/ASSE Z244.1, 2016; CSA Z460, 2013) and regulation in Quebec (ROHS, 2017), and recommendations from the literature (Karimi et al., 2018) were considered.

Reese (2011) stated that a compliance audit tool must be based on legal requirements and regulations.

In the proposed tool, the purpose behind the pre-audit stage was that an audit of the application of lockout would not be effective without the verification of the lockout procedures, equipment/machines and training records of authorized employees. It should be completed before the audit of the application of lockout takes place. Grund (1995) and Kelley (2001) stated that, before auditing the application of lockout, a review of procedures, the physical condition of equipment and documents is necessary.

Bigelow and Robson (2005) indicated that audit tools, based on an extensive review of accident causation and best practices in safety, may have some evidence of content validity. In testing audit tools for content validity, Robson et al. (2012) found that out of 17 safety audit methods, only five audit methods have been tested for content validity. The authors also demonstrated that the content of those five audit methods was incomplete, or only partially complete, in accordance with relevant safety standards and therefore content validity was very low in those methods. Huang and Brubaker (2006) showed that the content validity of the audit tool is important in order to have a reliable tool, for example, a high level of internal consistency and reliability. In the present study, the results showed that the tool had high content validity index scores in terms of both the content validity index for items (I-CVI) and content validity index for the tool (S-CVI). With regard to having excellent content validity, Polit and Beck (2006) proposed that both I-CVI and S-CVI be calculated for the scale being judged. The authors recommended that a valid scale requires a minimum I-CVI of .78 (for 6-10 experts as explained by Lynn (1986)) for each item and a minimum average S-CVI of .90 for the scale. Our results exceeded these expectations. Lynn (1986) recommended two rounds of expert evaluations in the event there is the need to improve upon the items. In our study, the levels suggested for content validity were achieved in the first round. The experts confirmed the relevancy of all statements and also found that the tool was clear and understandable.

Moreover, all the organizations (6/6), specifically their internal auditors, had no difficulty understanding the content of the tool and using the tool on actual lockout practices, since the tool comprises clear and understandable content (checklist statements) and includes examples for some statements in order to reduce incorrect interpretation. They were also positive about using our tool and found it useful and applicable. This was expected, since their tools were incomplete, and did not cover all the requirements in the North American standards and Quebec regulation for the implementation of lockout.

Although this study demonstrated significant results with regard to content validity of the tool, it had some limitations. The primary limitation of this study was that inter-rater reliability (the consistency among auditors) of the tool was not tested. However, general instructions and a brief guide for each stage of the audit (i.e. pre-audit and audit) were prepared in the tool. Moreover, the checklist statements in the tool were clear and there was no need for interpretation. Reliability might be increased by adding some guidance in the audit tool (Kuusisto, 2000), and the subjectivity could be minimized when the content is valid, understandable, and free from judgment and influence (Muckler & Seven, 1992).

The application of alternative methods to lockout (for the control of hazardous energy) was excluded from this study. In future research, developing a self-auditing tool for the control of hazardous energy, where alternative methods to lockout are included could be developed. Karimi et al. (2019), and Poisson and Chinniah (2016) showed that the application of alternative methods was not compliant with the relevant standards and regulations within organizations and they need to increase their knowledge about alternative methods. As such, tests for inter-rater reliability would be important in developing a self-audit tool for the application of alternative methods.

6.5 Conclusions

According to the literature, despite the importance of periodic audit/inspections of the application of lockout procedures in relevant standards and regulations, numerous organizations have no access to a valid or accurate self-audit tool for conducting audits of the application of lockout on machinery, i.e. without external auditors. In this paper, a specific tool for the self-assessment of the application of lockout is presented. The content validity of the tool was tested via a panel of six experts and the results showed the highest validity index scores. The tool was tested by six organizations on different equipment. The feedback from them demonstrated that the tool covered most of the expectations of the organizations, and the content of the tool was clear and understandable for internal auditors who were knowledgeable about lockout. Furthermore, the tool was easy to use and applicable. In summary, the applicability, completeness and comprehensiveness of the self-audit tool were adequate. This self-audit tool will help organizations assess the application of lockout, find deviations and deficiencies, and take corrective actions related to their lockout program and procedures.

Author Contributions: Conceptualization, B.K., D.B.V. and Y.C.; Methodology, B.K., D.B.V. and Y.C.; Validation, Y.C. and D.B.V.; Formal analysis, B.K. and D.B.V.; Investigation, B.K., D.B.V. and B.A.; Writing – original draft, B.K.; Writing – review & editing, B.K., D.B.V., Y.C. and B.A.; Supervision, Y.C.; Project administration, D.B.V. and Y.C.; Funding acquisition, B.K., D.B.V., Y.C. and B.A.

Funding: This research was supported by the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), Grant number 2015-0015; and the Natural Sciences and Engineering Research Council (NSERC)- Discovery Grants Program – Individual, Grant number RGPIN-2017-05629.

Acknowledgments: The authors wish to thank the organizations that agreed to participate in this study. They also wish to thank the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), as well as NSERC for funding this research.

Conflicts of Interest: The authors declare no conflict of interest.

CHAPTER 7 GENERAL DISCUSSION

In this thesis, several qualitative studies were conducted to shed more lights on the control of hazardous energies in organizations in order to find the state of the art, shortcomings, and problems of the actual practices of lockout and alternative methods, and finally to develop a self-audit tool for monitoring the application of lockout. This chapter summarizes the main findings of the thesis were obtained from: (i) investigating the application of lockout program and procedures in organizations presented in Chapter 4; (ii) study of alternative methods to lockout that are used in organizations investigated in Chapter 5; and (iii) design and development of a self-audit tool for the application of lockout presented in Chapter 6.

7.1 Key findings of the investigation on the actual practices of controlling hazardous energies

In this thesis, although some positive results regarding lockout and alternative methods were found in the organizations studied, considerable improvements were needed. For example, the organizations had more difficulties in using alternative methods, specifically performing risk assessment, than the application of lockout. Moreover, in terms of using alternative methods, a need for clarification on the standard and regulation, especially on the Quebec regulation was demonstrated. In spite of the fact that practical training and proper tools for audits are important factors in the control of hazardous energies and are essential to ensure safety of workers, the lack of audit tools and practical training were found in most of the organizations. The following sub-sections present the key findings and will discuss the research results.

7.1.1 Need for clarification on the Canadian standard and Quebec regulation

In terms of alternatives to lockout, the Quebec regulation does not provide the detailed information and some sections of the regulation (i.e. art. 188.2 and art. 189) are not clear to understand, hence compounding problems. Indeed, the regulation makes an unclear exclusion from lockout and also alternative methods where the machine is equipped with a specific control mode. This exclusion is not in accordance with the Canadian standard CSA Z460 (2013), American standard ANSI Z244.1 (2016), and ISO 12100 (2010). This research revealed that this exclusion should be an alternative method to lockout. For example, using a specific control mode can be an alternative method when performing a task in the danger zone of a machine with this control mode allows the dangerous parts of the machine to be operated only (i) by using a control device requiring continuous action; or (ii) by using a two-hand control device; or (iii) by a continuous action of a validation device; or (iv) at reduced speed, under reduced tension, step-by-step; or (v) by means of a separate step control device. In addition to the regulation, the Canadian standard CSA Z460 (2013) provides fewer details about selecting alternative methods. By comparison with the American standard ANSI Z244.1 (2016) that provides more details about evaluating alternative methods (clause 8.2) and reliability/effectiveness of alternative methods (clause 8.3), these explanations are not mentioned in the current Canadian standard and would be embedded in the next revision of the standard.

These clarifications are important for organizations to determine which method (i.e. lockout, alternative methods or a combination of these) is appropriate to control of hazardous energy, and also to prevent interpretation that can be very subjective.

7.1.2 Incomplete lockout programs

Several elements in the written lockout programs of the organizations studied were missing. Target equipment and lockout devices/ hardware were not mentioned in over half of the lockout programs. The definition of alternative methods to lockout (including specific instructions) was missing in 75 percent of the programs. Risk assessment was found in no programs. Validation of lockout placards before using mentioned in only half of the programs. Training documentation and retraining program were not presented in over half of the programs. Sub-contracting/ external services (supervision, authorization, role and responsibilities) were found in no programs. Finally, audits/inspections were not mentioned in almost all the programs. Despite the fact that the lockout programs were incomplete in some organizations studied, the actual practice of lockout was better than what was explained in the lockout programs. It shows that the lockout program is not always a proper measure of actual lockout practices in organizations. Recommendations for addressing these shortcomings were presented in Chapter 4.

7.1.3 Neglecting to read lockout placards

Although the organizations provided lockout placards (i.e. procedures specifically for the task/equipment/ machine) and placed them next to the equipment/machines, it was found that employees in almost all the organizations only sometimes read them when applying lockout. Moreover, in the case of implementing the group lockout approach, only the principal authorized employee read placards. Being confident about applying lockout without the need of placards especially among experienced worker, or no easy access to placards could be the main reasons for compromising reading them. Neglecting to read placards can be problematic, particularly when the placards have been updated or workers have limited experience or are unaware of changes. Recommendations for addressing these shortcomings were presented in Chapter 4.

7.1.4 Absence of supervision of subcontractors and coordination of the roles and responsibilities

Whereas some organizations systematically used the lockout box as a structural element for the continuity of lockout or the supervision of subcontractors, absence of the coordination of the roles and responsibilities when outsourcing of tasks to several existing subcontractors was found in about 70 percent of the originations. The findings showed that the validation of subcontractors' qualifications and competencies was compromised in all the organizations. In three organizations subcontractors were considered to be specialists in the equipment concerned, and the organizations justified the lack of supervision on this basis.

Furthermore, no verification of subcontractor's training was found in more than half of the organizations. The findings also showed the lack of supervision of subcontractors and it was justified because the organizations considered them as specialists. The level of control (i.e. supervision of subcontractors) varied from one organization to another. It was demonstrated that the organizations had no specific audit process and tool to monitor subcontractors' lockout activities. It is more problematic, especially when subcontractors follow their own lockout procedures (not the host procedures). Chapter 4 presented the recommendations for addressing these shortcomings.

7.1.5 Absence of a complete training program

Lack of practical training was found in over half of the organizations and no practical training was found specifically for using alternative methods to lockout. Moreover, the understanding of the lockout program was not part of training in 70 percent of the organizations. No training program related to the application of lockout for subcontractors was found. Although the organizations stated that they had retraining programs, the content of this refresher training (retraining) was not based on known hazards and risk assessment for the planned work activities/conditions. Documentation of retraining was not complete in most of the organizations. Recommendations for addressing these shortcomings were presented in Chapter 4.

7.1.6 Lack of risk assessment for using alternative methods

The findings indicated that almost 80 percent of the organizations applied alternative methods without performing risk assessment before using them. In fact, they carried out the risk assessment only for safe operation on machines and not for using alternative methods. Additionally, the lack of appropriate tools for risk estimation was found. Moreover, it was found no documentation concerning risk analysis results. It is very important since not performing risk assessment before using alternative methods to lockout to ensure equivalent safety causes serious injuries and deaths. Recommendations for addressing these shortcomings were presented in Chapter 5.

7.1.7 Noncompliant application of alternative methods

The findings demonstrated over 70 percent of the organizations had no technical knowledge about alternative methods. Despite the fact that almost all the organizations used alternative methods to lockout, the application of alternative methods was not in compliance with the standard (CSA Z460, 2013), Quebec regulation (ROHS, 2017) and other relevant standards (e.g. ISO 13849-1, 2015). Over half of the organizations had no procedure for alternative methods and in the procedures used in the rest of organizations some main steps of the general procedure of alternative methods were missing. Little understanding of the Quebec regulation (ROHS art. 188.2, 189.1) requirements, and also of the standard ISO 12100 (2010) about reduced-speed or reduced-force work was found. Chapter 5 presented the recommendations for addressing these shortcomings.

7.1.8 Lack of audit tools and documentation of audit results

The findings showed a lack of the valid and comprehensive audit tool for lockout in all the organizations studied. Although almost half of the organizations stated that they had tools for audit and inspection of lockout, those were simple checklists which contained only a few questions about lockout. Audits must be designed to correct any observed deviations or inadequacies. The findings demonstrated that the lockout audit was part of the general safety audit in most of the organizations and audit results were not used specifically for lockout. It was also found that only two out of fourteen organizations documented audit results. Chapter 5 presented the recommendations for addressing these shortcomings.

7.2 Extended discussion

The following sections discuss the aforementioned findings with regard to the research contributions.

7.2.1 Research contributions

In terms of theoretical and methodological contribution, in this study, a comprehensive questionnaire (more than one hundred questions) for investigating the actual practices of application of lockout program, procedures and alternative methods was developed based on the review of the literature and comprised all the main factors of the control of hazardous energies and covered the requirements of Canadian standard and Quebec regulation. Moreover, the comprehensive self-audit tool for the application of lockout was developed based on all the requirements of the relevant standards (i.e. CSA Z460, 2013 and ANSI/ASSE Z244.1, 2016), Quebec regulation (ROHS, 2017), and findings from the previous steps of this research (i.e. Chapter 4 and 5). The novel tool serves as checklist statements and makes it possible to assess both the preparation of the lockout with a pre-audit stage and the application of the procedures (i.e. the audit stage) as such. The pre-audit stage helps organizations to verify the availability and content of lockout procedures, the availability, and condition of lockout materials/hardware, and the training records of authorized employees/ external services. Additionally, the required actions were defined and embedded in the pre-audit stage to aid organizations to address the problems (deficiencies) found during the pre-audit. Chapter 6 presented the details of the development of this tool.

In terms of practical contribution, the application of lockout and alternative methods was evaluated in 14 organizations and the shortcoming, gaps, and best practices were identified. Based on literature review, relevant standards and regulations, the recommendations and corrective actions to address the shortcomings in lockout program and actual practices of lockout procedures and alternative methods were proposed. Furthermore, the content validity of the proposed self-audit tool was tested through the panel of experts and the six organizations selected. It was found that the tool had high content validity index scores (Lynn, 1986; Waltz et al., 2005) in terms of both the content validity index for items (I-CVI) and content validity index for the tool (S-CVI). Indeed, the results exceeded the expectations of content validity for the items and the tool. Lynn (1986) recommended two rounds of expert evaluations in the event there is the need to improve upon the items. In this study, the levels suggested for content validity were achieved in the first round and thus there was no need for the second round. The experts confirmed the relevancy of all statements and also found that the tool was clear and understandable.

Moreover, all the six organizations, specifically their internal auditors, had no difficulty understanding the content of the tool and using the tool on actual lockout practices, since the tool comprises clear and understandable content (checklist statements) and includes examples for some statements in order to reduce incorrect interpretation. They were also positive about using our tool and found it useful and applicable. This was expected, since their tools were incomplete, and did not cover all the requirements in the North American standards and Quebec regulation for the implementation of lockout. It was also demonstrated that the proposed self-audit tool was adequately complete and comprehensive.

7.2.2 Research outcomes and improving the application of lockout

The thesis showed that the application of lockout and alternative methods was not fully in compliance with the Canadian standard and Quebec regulation. It can lead to a high risk of injuries or fatalities. Although the organizations studied had had no serious accidents linked to the control of hazardous energy in recent years, half of the organizations had experienced near-miss incidents that could be signals of safety problems. The findings also reflected why these shortcomings and problems existed in the organizations studied. In summary, the low awareness of the requirements of the regulation and standard in force, lack of practical training, and the absence of audits (to identify and to correct deficiencies or gaps) were the most important factors. In this regard, organizations must keep their control energy programs (i.e. lockout programs) updated in accordance with the regulation and the standard in force. Most importantly, organizations should consider the audit as a continuous process (not a one-off action), and conduct audits to (i) find shortcomings and problems in the application of controlling hazardous energies (e.g. shortcoming in lockout procedures and workers' knowledge or training); (ii) correct the deficiencies in accordance with normative and regulatory requirements, and organizations' expectations. Studies showed that having a valid and comprehensive self-audit tool is necessary and important to conduct audits and monitor the application of controlling hazardous energy (Yamin et al., 2017; Esposito, 2009; Grund, 1995; Reese, 2011). Indeed, without a valid and comprehensive self-audit tool, it is not guaranteed that the audit results are accurate and reliable. The findings of this research showed that the developed self-audit tool proved to be valid (in terms of content validity) and applicable. Thus, it is concluded that the self-audit tool helps organizations not only to identify deficiencies and shortcomings in the application of lockout, but also to correct them and improve lockout practices. Additionally, the tool can be tailored to the company needs and by using this self-audit tool, the need for costly site assessments by external auditors can be eliminated and internally evaluating lockout practices in a large number of organizations, especially small and remote organizations, can be facilitated. Moreover, organizations with no previous experiences in lockout practices might have difficulty understanding the requirements in Canadian standard or Quebec regulation, and therefore they can take advantage of using this tool to determine the pre-requirements and requirements of the application of lockout, which were explained in the self-audit tool and to apply lockout properly and also to monitor their lockout practices.

CHAPTER 8 CONCLUSION AND RECOMMENDATIONS

This last chapter summarizes the advancements presented in this thesis, the research limitations and constraints, and the main recommendations for future research.

8.1 Advancement of knowledge

In summary, in this thesis the following advancements were made:

- For the first time, a comprehensive study on the application of lockout program and procedures for the control of hazardous energy on machinery in different organizations was carried out. The shortcomings were recognized and the recommendations/corrective actions to address them were proposed.
- A detailed scientific study on the application of alternative methods on machines operating in different sectors, where the same regulation applies, was conducted. This study is a first reference point on using alternative methods to lockout and it can enrich the understanding and practice of organizations.
- A valid and comprehensive self-audit tool for the application of lockout to control hazardous energies was developed and developed. The tool encompasses all of the normative and regulatory requirements of the application of lockout procedures. The novel tool is not only to monitor the actual lockout practice also it defines the actual procedures to audit, as well as the surrounding conditions that are needed. The tool is complete, easy to use, serves as a checklist and is practical in order to help organizations conduct internal audits of the application of lockout, find and correct gaps and shortcomings, improve the application of lockout, and ensure the safety of workers. Finally, the self-audit tool can be adapted to the organization needs.

8.2 Research limitations and constraints

- The first limitation of this research was that the organizations studied (14) were a non-random sample. It was a compromise involving the recruiting challenges (e.g. resources available) and the need to explore a range of work situations. However, the organizations recruited were diverse in terms of industry, size, and machinery/equipment. Thus convenience sampling (is not a purposive strategy) was selected as the sampling strategy to save time and effort through collecting information from maximum participants who are accessible.

- The second limitation of this study was that the tool was only tested for content validity. Indeed, the tool is valid in terms of the assessment of content validity. The other types of contrast validity were not evaluated due to the scope of research and the limited number of organizations recruited (six organizations). Furthermore, the applicability and usability of the tool were based on the simple questions provided for the organizations which had previous experiences in audits of lockout. In fact, the scientific methods in the literature for usability measurement of the tool were not used in this study, thus the results might be different if other methods were or a different number of participants was recruited.
- The third limitation of this study was that the test for inter-rater reliability (the consistency among auditors) of the tool was not carried out. However, the tool consisted of general instructions and a brief guide for each stage of the audit (i.e. pre-audit and audit), as well as the clear checklist statements so that subjectivity was minimized.
- The last limitation of the research was that a self-audit tool for the application of alternative methods was not proposed. The proposed self-audit tool is the appropriate tool to monitor and evaluate the application of lockout in organizations.

8.3 Main recommendations for future research

For future research, it would be valuable to research this topic in heavy and process industries (e.g. oil and gas or mining), which have complex machinery, or in different countries with various regulations and standards that are different from the North American standards and regulations.

A test for reliability (i.e. inter-rater reliability) of the proposed self-audit tool can be useful to ensure that the tool is applicable and usable in companies with low experience in the application of lockout. For high reliability, a higher number of companies would be recruited. Moreover, the other types of construct validity can be tested.

A valid and reliable self-auditing tool for the control of hazardous energy, where alternative methods to lockout are included could be developed.

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APPENDIX A QUESTIONNAIRE FOR DATA COLLECTION THROUGH INTERVIEWS

General information	
Organization	Name: Sector: Safety Committee: ☐ Yes ☐ No Number of employees:
Interviewees	Names: Responsibility/ Profession: Emails:
Interviewer	Name: Date:
Documentation collected	Lockout program ☐ Yes ☐ No Lockout procedure ☐ Yes ☐ No Alternative method procedures ☐ Yes ☐ No Training records and material ☐ Yes ☐ No Audit/inspection tool ☐ Yes ☐ No Audit records/reports ☐ Yes ☐ No Other:
Items	**Question contents**
General lockout program	Do you have a written program? Who developed the program? Why was it developed? For what reasons? What documents/sources were used to write it? How is the program used? How are the roles and responsibilities of managers, supervisors, maintenance personnel, and operation staff shared?
Application of lockout	Are there any equipment and machines that are not part of the lockout (and other methods)? If yes, why? What activities require lockout? Which are the most frequent? (Installation, Adjustment,

Questionnaire for data collection through interviews (cont.)

	Inspection, Disconnection, Setting, Service, Disassembly, Cleaning, Maintenance, Repair, etc.) What criteria do you use to determine whether an activity requires applying a lockout procedure? Which groups of workers are affected by the lockout? Which groups of workers apply lockout procedures? (Operators, Maintenance staff, Subcontractors) What types of lockout are practiced in the enterprise? [Individual, Group (1 box), Complex group (> 1 box)] Types of energy sources which are controlled? (Electric, Pneumatic, Mechanical, Chemical, Hydraulic, Thermal) How many lockout procedures/placards do you have (or is there to do)? Describe the process of creating and validating lockout placards? Items (contents) of lockout placard? (Based on the new regulation) What steps have been done to facilitate the understanding of placards and avoiding errors (e.g. photo, pictogram, etc.)? How many lockout procedures are applied per shift (approximately)? What is the average duration of a lockout procedure (application + Works + return to service)? What kinds of isolating devices do you use? What types of lockout devices and accessories do you use? Does the equipment have isolating devices which are close to or on the equipment? When purchasing equipment, do you look for equipment which can be easily locked? Lockout hardware and utilization principles? (Padlock unique, Keep the key under control at all times, Tags, Use of a hasp, Using the lockout box, Padlocking accessories) Do you have a night shift? Are there any differences in the application of lockout between a day shift and a night shift? How is the continuity in lockout ensured (e.g. during a change of shift or to indicate that the procedure is not completed)? Are there any difficulties of application in connection with the chosen method to ensure continuity?

Questionnaire for data collection through interviews (cont.)

	Do you have a procedure for withdrawing a padlock in the case of the absence of the person who put the padlock, or in the case of lost/forgotten key? Procedure content? In case the person is absent how is the padlock removed? Are there any difficulties related to the procedure of withdrawal padlock when the person who puts the padlock is absent?
Other methods of **Control of hazardous energies**	Do you have examples of non-application of a lockout procedure when it should have been? Do you have any disciplinary action in the case of non-application of lockout (e.g. verbal warning / leave/ etc.)? Do you have interventions where you do not lock out and use alternative methods (e.g. remote-controlled machinery)? Explain? What criteria are used to target tasks that require the application of other methods rather than lockout procedure? What are the alternative methods to lockout that you use? (i.e. moveable interlocked guard, which is locked in the open position with a padlock, control knob which is locked in the deactivated position with padlock, emergency stop button which is locked with a key or a padlock in the activated position, Safety device (curtain, laser, camera, safety mats) locked in the activated position, safety device without any locks, PPE, etc.) Do you have a written procedure for alternative methods to lockout? What is the content of the written procedure? To choose the alternative method to lockout, have you performed a risk analysis? Are the results of this risk analysis documented? What tool do you use for risk analysis? (Matrix, checklist, risk graph)
Sub-contractor (external services)	What activities (related to lockout procedures) are performed by sub-contractor? Do sub-contractors get written permission before undertaking work in the hazardous zone? When several subcontractors are involved in the hazardous area of equipment/machine, how is the work coordinated? How do subcontractors access the lockout placards or other methods for controlling energy? What type of lockout devices (e.g. padlock accessories) are used?

Questionnaire for data collection through interviews (cont.)

	How do subcontractors perform the verification test on the lockout procedure? Do you ensure that sub-contractors have received sufficient training on lockout or other energy control methods? If yes, how?
Training and records	What are the objectives and content of training (i.e. Practical or theoretical, duration, demonstration, training modules, individual or group, etc.)? Is there any specific training for the types of interventions or group of employees? How is the training of new worker carried out? Is there any assessment at the end of the training? What are the frequency and the reasons for retraining of personnel?
Audit/ inspections	Are the audits of lockout program, procedures and alternative methods performed? By whom? For what reasons? At what frequency? How do you proceed? With what tools? What are the results? What are problems and limitations which are identified? How do you use the results of the audits? How are corrective measures done? Are the audit tools and results available? Do you have examples of accidents or near misses caused by gaps in the application of lockout?
Other	Do you have other difficulties in connection with the lockout or other energy control methods? Do you have other solutions in connection with the lockout or other energy control methods?

APPENDIX B CERTIFICATE OF ETHICAL CONFORMITY

POLYTECHNIQUE MONTRÉAL
LE GÉNIE EN PREMIÈRE CLASSE

CERTIFICAT DE CONFORMITÉ ÉTHIQUE

Le 1er décembre 2016

M. Yuvin Chinniah
Département de mathématiques et génie industriel
Polytechnique Montréal

N/Réf : Dossier CÉR-1516-65 (UBR 3900048)

Monsieur,

J'ai le plaisir de vous informer que les membres du Comité d'éthique de la recherche (CÉR) ont procédé à l'évaluation en comité restreint de votre projet de recherche intitulé « *Étude sur la pratique du cadenassage sur des machines* ».

Les membres du CÉR ayant examiné votre projet en ont recommandé l'approbation sur la base de la documentation amendée que vous nous avez fait parvenir en date du 30 novembre.

Veuillez noter que le présent certificat est valable pour une durée d'un an, soit du **1er décembre 2016 au 30 novembre 2017**, pour le projet tel que soumis au Comité d'éthique de la recherche avec des êtres humains.

Nous vous saurions gré de nous faire parvenir un bref **rapport annuel** (http://www.polymtl.ca/recherche/document/deonto.php) afin de renouveler votre certificat au moins un mois avant l'expiration du présent certificat. La secrétaire du Comité d'éthique de la recherche avec des sujets humains devra également être informée de toute modification qui pourrait être apportée ultérieurement au protocole expérimental, de même que de tout problème imprévu pouvant avoir une incidence sur la santé et la sécurité des personnes impliquées dans le projet de recherche (sujets, professionnels de recherche ou chercheurs).

Je vous souhaite bonne chance dans vos travaux de recherche,

Delphine Périé-Curnier, présidente
Comité d'éthique de la recherche avec des êtres humains

c.c.: Céline Roehrig (DRIAI), Danielle Bilodeau (BRCDT), Brigitte Coté (Finances)

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APPENDIX C CALCULATION OF I-CVI AND S-CVI FOR THE INITIAL SELF-AUDIT TOOL

Calculation of I-CVI and S-CVI for the initial Self-audit tool: Pre-audit of the application of lockout

Item	Statement	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Number in Agreement	I-CVI
1	The equipment/machine/process has a written lockout procedure for the targeted task	*	*	*	*	*	*	6	1.00
2	The procedure has been updated or modified based on recent changes in the selected machine/equipment	*	*	*	*	*	*	6	1.00
3	The equipment/machine is in good condition (operating status, energy cut-off points, control system, guards and safeguards, etc.)	*	*	*	*	*	*	6	1.00
4	Identification of the equipment/machine	*	*	*	*	*	*	6	1.00
5	Identification and location of every control device and every energy source of the equipment/machine	*	*	*	*	*	*	6	1.00
6	Identification of the person responsible for the lockout procedure	*	*	*	*	*	*	6	1.00
7	The type and quantity of material required for applying lockout	*	*	*	*	*	*	6	1.00
8	Deactivation and complete shutdown of the equipment/machine	*	*	*	*	*	*	6	1.00
9	Elimination or, if that is impossible, control of any residual or stored energy source	*	*	*	*	*	*	6	1.00
10	Lockout of the equipment/machine’s energy source cut-off points	*	*	*	*	*	*	6	1.00
11	Verification of lockout by using one or more techniques making it possible to reach the highest level of efficiency	*	*	*	*	*	*	6	1.00
12	Safely unlocking and re-operating the equipment/machine	*	*	*	*	*	*	6	1.00
13	Where appropriate, the required personal protective equipment or any other complementary protection measure	*	*	*	*	*	*	6	1.00

Calculation of I-CVI and S-CVI for the initial Self-audit tool: Pre-audit of the application of lockout (cont.)

14	Where appropriate, identification of the transfer of responsibilities or required material to ensure the continuity of lockout during a staff rotation/shift change	*	*	*	*	*	*	6	1.00
15	Each authorized employee(s) (who will be audited) has been trained or retrained if needed	*	*	*	*	*	*	6	1.00
16	In the case of the external services, a written authorization has been issued for the external services before undertaking work in the danger zone	*	*	*	*	*	*	6	1.00
17	Appropriate lockout hardware for each type of energy control point of the equipment/machine are available and easily accessible in a lockout station or next to machinery	*	*	*	*	*	*	6	1.00
18	Authorized employees get appropriate lockout equipment and devices (e.g. lockout box, padlocks)	*	*	-	-	-	*	3	0.5
									S-CVI = Mean I-CVI = 0.972

I-CVI, item-level content validity index. S-CVI, scale-level content validity index.

Rating by six experts: items rated 3 or 4 on a 4-point relevance scale (1. irrelevant; 2. somewhat relevant; 3. relevant; and 4. highly relevant).

Calculation of I-CVI and S-CVI for the initial Self-audit tool: Audit of the application of lockout

Item	**Statement**	**Expert 1**	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**	**Expert 6**	**Number in Agreement**	**I-CVI**
1	The lockout procedure is easily accessible to the authorized employee (e.g. posted near the equipment, available on the intranet)	*	*	*	*	*	*	6	1.00
2	Authorized employees search for the lockout procedure and read its contents	*	*	*	*	*	*	6	1.00
3	Affected employees are notified before applying the lockout procedure	*	*	*	*	*	*	6	1.00
4	The authorized employees identify all hazardous energy sources of the equipment/ machine to be locked out (as per the procedure)	*	*	*	*	*	*	6	1.00
5	The equipment/machine is shut down by using normal stopping procedures (e.g., putting a switch in the “off” position)	*	*	*	*	*	*	6	1.00
6	The equipment/machine is isolated	*	*	*	*	*	*	6	1.00

Calculation of I-CVI and S-CVI for the initial Self-audit tool: Audit of the application of lockout (cont.)

	from every energy source (e.g., close valves, switch off main disconnects, switch off circuit breakers)								
7	The authorized employees apply hasps and their personal padlocks and information tags in accordance with the lockout procedure	*	*	*	*	*	*	6	1.00
8	All potential residual hazardous energies are relieved, disconnected, or restrained	*	*	*	*	*	*	6	1.00
9	The verification step (verification of isolation) is performed according to the established procedure to ensure that the equipment/machine cannot be operated	*	*	*	*	*	*	6	1.00
10	In the case of more than one authorized employee working on equipment, all employees affix their own (personal) padlocks according to the established procedure	*	*	*	*	*	*	6	1.00
11	In the case of personnel or shift change, the authorized employee follows the instruction to ensure the continuity of lockout, as mentioned in the procedure	*	*	*	*	*	*	6	1.00
12	Before lockout removal, authorized employees verify that the affected employees are safe and away from the equipment	*	*	*	*	*	*	6	1.00
13	Padlocks are only removed by the authorized employees who applied them	*	*	*	*	*	*	6	1.00
14	The equipment/machine is resupplied according to the established procedure	*	*	*	*	*	*	6	1.00
15	The authorized employees start the equipment and check that everything is working properly and that the work is finished (e.g. ensure that all work and interventions are completed)	*	*	*	*	*	*	6	1.00
16	All affected employees are notified of the completion of the intervention	*	*	*	*	*	*	6	1.00
17	The application of the procedure is recorded according to the established procedure	*	*	*	*	*	*	6	1.00
									S-CVI = Mean I-CVI = 1.00

I-CVI, item-level content validity index. S-CVI, scale-level content validity index.

Rating by six experts: items rated 3 or 4 on a 4-point relevance scale (1. irrelevant; 2. somewhat relevant; 3. relevant; and 4. highly relevant).