POLYTECHNIQUE MONTRÉAL

affiliée à l'Université de Montréal

Identification of Contributing Factors in Occupational Accidents in the Food and Beverage Industry and Proposing Solutions to Overcome Them

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présenté par **Alireza MAHDIUN**

en vue de l'obtention du diplôme de *Maîtrise ès science appliquées*

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DEDICATION

To all engineers with their endeavors for a better tomorrow

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RÉSUMÉ

Atteindre les objectifs de production et de fabrication à grande échelle sans l'utilisation de machines et d'équipements n'est pas possible. Cependant, la nécessité pour les travailleurs d'intervenir sur les machines et d'effectuer des tâches non routinières telles que le nettoyage, l'entretien et le dépannage est inévitable. L'industrie alimentaire et des boissons fait partie des secteurs dans lesquels de nombreuses machines et équipements sous tension sont opérationnels. En raison des exigences d'hygiène strictes, des réglementations de qualité et des systèmes de gestion tels que l'analyse des risques et la maîtrise des points critiques (HACCP), les interventions des travailleurs sur les machines pendant le nettoyage sont fréquentes et inévitables. Le nettoyage dans l'industrie alimentaire et des boissons est généralement effectué dans des conditions difficiles nécessaires pour atteindre les objectifs d'hygiène. Ces conditions incluent le port de vêtements et de masques spéciaux, l'exécution de tâches de nettoyage à l'intérieur d'espaces confinés (tels que des récipients avec de l'eau chaude tout en transportant des outils tels que des brosses), le transport des tuyaux lourds, et être en contact avec des pièces mobiles dangereuses.

Des méthodes de prévention des accidents telles que le cadenassage a été introduit depuis des années et recommandé par des règlements et des normes. Néanmoins, le nombre d'accidents mortels et graves dans l'industrie agroalimentaire lors de tâches non routinières reste élevé. Par conséquent, l'objectif principal de cette recherche est de procéder à une revue de littérature des bases de données sur les accidents survenus lors de travaux non routiniers dans l'industrie agroalimentaire. De plus, les rapports d'enquête sur les accidents dans la province de Québec sont étudiés et analysés. Le causes et les facteurs contributifs qui mènent aux accidents, ainsi que les mesures de prévention et de réduction des risques afin, sont présentés. En se basant sur les résultats de cette analyse, une liste de vérification est fournie pour faciliter l'évaluation de la sécurité au travail dans l'industrie alimentaire et des boissons. Ensuite, une étude de cas basée sur l'un des rapports d'accident est menée en utilisant la liste de vérification proposée, pour vérifier son efficacité. Enfin, des recommandations et des solutions pour l'amélioration de la sécurité dans l'industrie agroalimentaire sont proposées.

L'examen de la littérature a révélé que la productivité, la conception des équipements, la sous-déclaration des accidents, la culture de la sécurité, la formation et une gestion déficiente de la sécurité sont les causes et les facteurs contributifs aux accidents les plus signalés dans l'industrie agroalimentaire. Vingt-quatre déclarations d'accidents mortels ou graves survenus au Québec entre l'année 2000 et 2021 sont analysées en tenant compte de ces facteurs. Pour ces rapports analysés, la gestion déficiente de la sécurité, qui comprend un manque de supervision, des mesures correctives, des évaluations des risques et l'absence de procédures de travail, est la cause la plus fréquentes des accidents graves et mortels. De plus, l'absence de plans de maintenance préventive complets, de manuels de machines, de procédures de travail, l'absence de cadenassage et le retrait des protecteurs ont également été identifiés comme des facteurs de risque aux accidents.

La mise en œuvre de la maintenance productive totale (TPM), la prise en compte des tâches de nettoyage lors de la conception des machines et des équipements tels que les cuves autonettoyantes et l'utilisation de systèmes de nettoyage en place automatisés pour le nettoyage sont recommandées comme bonnes pratiques pour minimiser les risques d'accidents.

De plus, quelques bonnes pratiques d'autres industries qui sont adaptables à l'industrie des aliments et des boissons sont recommandées pour les études futures. Par exemple, l'utilisation de systèmes de surveillance autour des machines dangereuses et l'utilisation de passeports de sécurité pour enquêter sur la formation font partie de ces recommandations.

ABSTRACT

Achieving production and manufacturing targets on a large scale without using machines and equipment is not possible. However, the need for workers to intervene with machines and perform planned or unplanned non-routine tasks such as cleaning, maintenance, and troubleshooting is inevitable. The food and beverage industry is among the sectors in which numerous energized machines and equipment are operational. Due to the strict hygiene requirements, quality regulations, and management systems such as hazard analysis and critical control points (HACCP) workers' interventions with machines during cleaning are frequent and unavoidable. Cleaning in the food and beverage industry is usually done under challenging conditions necessary to achieve hygienic goals. These conditions include wearing special clothes and masks, performing cleaning tasks inside confined spaces (such as vessels with hot water while carrying tools such as brushes), carrying heavy hoses, and being in contact with dangerous moving parts.

Accident prevention methods such as lockout have been introduced for years and are recommended by regulations and standards. Nevertheless, the number of fatal and serious accidents in the food and beverage industry during non-routine tasks remains high. Therefore, the main aim of this research is to conduct a literature review of databases on the accidents that occurred during non-routine work in the food and beverage industry. Furthermore, the accident investigation reports in the province of Quebec are studied and analyzed. Main causes and contributing factors that lead to the accidents and risk reduction measures to minimize the occurrence of accidents and injuries are studied. Based on the findings, a comprehensive checklist is provided to facilitate the assessment of occupational safety in the food and beverage industry. Then, a scenario-based case study is performed using the proposed checklist and one of the accident reports, to verify the effectiveness of the checklist. Finally, recommendations and solutions for improving safety in the food and beverage industry are proposed.

The literature review revealed that productivity pressure, poor equipment design, underreporting of accidents, safety culture, training of workers, and deficient safety management are the most reported causes and contributing factors in the food and beverage industry accidents. Twenty-four fatal or serious accident reports that occurred in Quebec between 2000 to 2021 are analyzed considering these factors. In these accident reports, deficient safety management, which includes

lack of supervision, corrective actions, risk assessments, and the absence of working procedures, was the most common cause to accidents. Also, the lack of comprehensive preventive maintenance plans, machine manuals, working procedures, absence of lockout, and removed guards were identified as causes and contributing factors.

Implementing total productive maintenance (TPM), consideration of cleaning tasks in the design stage of the machines and equipment such as self-cleaning vessels, and use of automated cleaning in place (CIP) systems for cleaning are good practices to minimize the risk of accidents.

Additionally, a few good practices from other industries adaptable to the food and beverage industry are recommended for further study and research. For instance, these recommendations include using surveillance systems around hazardous machines and using safety passports to investigate the training.

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LIST OF SYMBOLS AND ABBREVIATIONS

AFIM	Association Française des Ingénieurs et Responsables de Maintenance
ANSI	American National Standards Institute
ASSE	American Society of Safety Engineers
BLS	Bureau of Labor Statistics
CCP	Critical Control Points
CCTV	Closed Circuit Television
CFIA	Canadian Food Inspection Agency
CIP	Cleaning in place
CNAMTS	Caisse Nationale d'Assurance Maladie des Travailleurs Salaries
CNESST	Commission des Normes, de l'Equité, de la Santé et de la Sécurité du Travail
CSA	Canadian Standards Association
CSST	Commission de la santé et de la sécurité du travail
FDA	Food and Drug Administration
FMEA	Failure Mode and Effect Analysis
GMP	Good manufacturing practices
HACCP	Hazard Analysis Critical Control Point
HSE	Health and Safety Executive
HSL	Health and Safety Laboratory
INRS	Institut national de la recherche scientifique
IRSST	Institut de recherche Robert-Sauvé en santé et en sécurité du travail
ISO	International Organization for Standardization
NAICS	North American Industry Classification System
NIOSH	National Institute for Occupational Safety and Health

NIST	National Institute of Standard and Technology
OSHA	Occupational Safety and Health Administration
PPE	Personal Protective Equipment
RCM	Reliability Centered Maintenance
ROHS	Regulation respecting Occupational Health and Safety
RSST	Règlement sur la santé et la sécurité du travail
SSOP	Sanitation Standard Operating Procedures
STAMP	Systems Theoretic Accident Model and Processes
UK	United Kingdom
USDA	United States Department of Agriculture
WCB	Workers Compensation Board
WSIB	Workplace Safety and Insurance Board

CHAPTER 1 INTRODUCTION

Utilizing machines in different industry sectors such as agriculture, pulp and paper, energy, food and beverage, and manufacturing is common. Failure in machinery can cause a stoppage in the production, and workers usually need to intervene with machines to solve the issue. Similarly, non-routine activities require workers to intervene with machines. These non-routine interventions include cleaning, maintenance, unjamming, and inspections and they can be either planned or unplanned. The intervention of humans with machines can be dangerous due to poor isolation and lack of hazardous energy controls (Chinniah, 2015). Based on a study carried out by the UK's health and safety laboratory (HSL), nearly one-third of human-machine accidents could have been prevented if the dangerous energies, were controlled and isolated from their sources (Shaw, 2010). Therefore, to provide the safety of workers who need to intervene with machines, the application of lockout or control of hazardous energies, is proved to be an effective method (CSA, 2020; 29 CFR 1910.147, 1989; ROHS, 2017).

Article 188.2 of occupational health and safety regulations in Quebec clearly states that "before undertaking any work in the hazardous area of a machine, in particular assembly, installation, adjustment, inspection, stripping, decommissioning, maintenance, disassembly, cleaning, maintenance, refurbishment, repair, modification or unblocking, lockout or, failing that, any other method that ensures equivalent safety, must be applied under this subsection." (The Ministère du Travail, de l'Emploi et de la Solidarité sociale, 2016). Although such regulations exist, poor application of energy isolation and padlocking while performing tasks in the hazardous area is one of the leading causes of fatal and serious accidents (Chinniah, 2015). Identifying these hazards and controlling and safeguarding them have been topics of codes and standards for years. Canadian Standard Association (CSA) Z 432-16, CSA Z 460-20, ISO 12100, OSHA 1910, and ANSI/ASSE Z244.1 provide the regulations for machine safety and lockout procedures.

In the food and beverage industry, in addition to the risks associated with machines, numerous activities can cause risks to the workers. Cleaning is one of the activities that require workers to work close to the moving parts of machines, enter confined spaces, use heavy hoses, use chemicals for sanitation, and work on slippery surfaces and in hot work environments (HSE, 2005). Although there are codes and standards for preventing such accidents, statistics show that fatal and serious accidents occur in the food and beverage industry. Based on the annual report of the Census of

Fatal Occupational Injuries of the U.S., 176 fatal accidents occurred in the food and beverage industries between 2015 and 2018 (BLS, 2019).

The food and beverage industry is the second largest manufacturing industry in Canada. 290,000 Canadians are employed in this sector (Government of Canada, 2021). Although different prevention and risk reduction measures such as application of lockout, installation of safeguards, permit to work, risk assessment, and risk management processes are in place, the accident rates in the food and beverage industry are high, and fatal and serious accidents occur. Considering the importance of this industry across Canada, the number of employees involved, and the number of accidents in this sector, it is essential to identify the causes and contributing factors to the accidents to minimize injuries and fatalities. Therefore, this study aims to identify and analyze the causes and contributing factors to the accidents related to non-routine tasks in the food and beverage industry by conducting a literature review. Accident investigations in Quebec were reviewed, and a checklist was provided as a self-assessment tool to identify the causes and contributing factors to accidents in the food and beverage industry.

To facilitate the understanding of the practices to prevent accidents and injuries caused by machines, chapter 2 presents the risk reduction process and lockout as a well-established method to minimize the risks of working with machines. It also shows the importance of the food and beverage industry, hygiene requirements, and procedures necessary to perform. Also, a review of the statistics of accidents in provinces of Canada will be presented in chapter 2.

In chapter 3, the research gap that triggered the idea of conducting this study, problems, main objectives, and the methods to achieve them are presented. Furthermore, the keywords used in the databases, and excluded items are explained.

Chapter 4 provides the results and introduces the checklist as an assessment tool. Also, as a sample, an assessment of a workplace by utilizing the checklist is presented in chapter 4.

In chapter 5, the conclusions of this study are explained in detail. Moreover, the limitation of this research and recommendations for future studies are presented.

CHAPTER 2 LITERATURE REVIEW

2.1 Machinery safety

ISO12100 defines a machine as equipment with a drive system that at least one of the connected components move during its function (ISO, 2010). Machines are formed of many moving parts, and in some cases, tasks need to be done by workers in close contact with moving parts. The failure of machines in automated production lines increases the need for humans to intervene with machines, and as a result, the possibility of accidents and injuries increases (Backström & Döös, 1997). Therefore, companies and regulators set rules and implement standards to mitigate technical as well as organizational or cultural causes of the failures to prevent accidents (Backström & Döös, 1997).

Accident reports are provided by Commission de la santé et de la sécurité du travail (CSST) in the province of Quebec. A study on machinery related accidents provided by CSST concluded that although safeguards namely barriers, interlocks, and presences sensors were in place to prevent accidents caused by contact with machinery, in many accidents, they were inadequately designed, bypassed, or were not functioning properly at the time of the accident (Chinniah, 2015). Another study over 457 human-machine accidents indicated that safeguards were absent in 32% of accidents (Charpentier, P., 2005).

A study on machine manufacturers and suppliers to identify the safety observation and documentation in production steps was conducted by Bluff et al. It was concluded that only a few firms performed comprehensive safety reviews, hazard identification, and implementation of risk control measures. Eliminating sources of hazards is the most effective if it is inherent in the design of a machine. Therefore, manufacturers must pay more attention during the design and manufacturing phase of the machines to achieve the goal of zero fatal and non-fatal accidents (Bluff, 2014, 2015; Kletz, 2003). Since hazards vary in different machines, risk assessments need to be done to identify the risks for particular machines (CSA, 2014).

2.1.1 Risk assessment and risk reduction measures

Risk assessment is a process that consists of the determination of limits, identification of hazards, risk estimation, and risk evaluation. It is followed by a hierarchy of risk reduction measures based on the level of risk reduction (CSA, 2020). In other words, the methods with the highest level of risk reductions and eliminations of hazards are the priorities. ISO 12100.2010 introduces risk assessment steps in machinery safety. The risk assessment process must follow the steps to evaluate the risks resulting from machinery. Consequently, the risk assessment is followed by a series of risk reduction measures and controls to eliminate or reduce the risks to an adequate level (CSA, 2014) and (ISO, 2010). The National Institute for Occupational Safety & Health (NIOSH) represents the list of controls shown in table 2-1, which introduces the most effective solutions.

Table 2-1 Hierarchy of controls provided by NIOSH (www.cdc.gov).

Controls	Explanation
Elimination	Hazards will be removed and eliminated (e.g., place the sampling point far from the hazardous moving parts).
Substitution	Hazards will be replaced by a less hazardous machine or process (e.g., using less toxic materials in the process).
Engineering Controls	Workers are isolated from the hazards (e.g., installing machine guards).
Administrative Controls	Changes in working methods (e.g., the use of signages and written working procedures).
PPE (Personal Protective Equipment)	Last option (e.g., gloves, safety shoes, goggles).

Highest — **Level of provided protection** — Lowest

Highest — **Effectiveness of control measures** — Lowest

The basic concept of the risk reduction hierarchy lies in each method's effectiveness, the most effective being the priority and vice versa. Eliminating hazards that remove the hazards entirely is the top priority in the hierarchy of controls. Replacing the hazards with a less hazardous process or machine (called substitution) is the second priority. The third priority is the engineering controls; by implementing them, workers are separated and isolated from the hazards. Engineering safeguards and controls must provide an equivalent level of protection as lockout protects workers (CSA, 2020). "Inherently safe design", "safeguarding and complementary protective measures" and "information for use (warning signs, handbooks)" shall be implemented at the design stage by the manufacturer. Protective measures need to be followed and implemented by users (organization, company, and operators), including "safe working procedures", "supervision, permit to work systems", "provision and use of additional safeguards", "use of personal protective equipment", and "training" (ISO*,* 2010). Table 2-2 presents more details in this regard. Due to the higher level of effectiveness, protective measures that can be applied during the design phase are more favorable than the measures that need to be performed by users.

Table 2-2 Protective measures implemented by designers and users according to ISO 12100, 2010 standard (ISO*,* 2010).

Protective measures by design	Protective measures by the user
• Inherently safer design • Safeguards and complementary protective measures • Information for use right next to the machine (Warning signs, warning devices) and in the manual	• Organization (safe working procedure, supervision, permit to work systems) • Provision and use of additional safeguards • Use of personal protective equipment • Training

After implementing risk reduction measures, if the residual risk is high and risk reduction is not achieved, lockout should be applied (CSA, 2020). In the next section, the lockout will be introduced.

2.2 Lockout

2.2.1 Introduction to lockout

In the manufacturing and production work environment, performing daily non-routine tasks such as unjamming, adjusting, cleaning, maintenance, troubleshooting, and replacing parts, involves human interventions with machines and equipment. Part of these interventions are planned, and some take place when an undesired or unplanned stoppage happens. The Annual report of the Census of Fatal Occupational Injuries of the U.S. states that in 2019 alone, 93 fatal accidents occurred due to being caught by energized machinery. Between 2015 and 2019, 452 accidents caused death from being caught in an energized and running equipment. Furthermore, another category mentioned that maintaining, repairing, and installing the machines were the occupations with 438 fatal accidents occurring in 2019 (BLS, 2019). Another study marks cleaning and repairing as two activities with the highest number of fatal and serious injuries due to the absence of lockout (Bulzacchelli et al., 2008). A study in South Korea in the manufacturing industries indicated that more than 50% of fatal accidents occurred during non-routine work. These fatal accidents occurred while performing tasks mostly on equipment such as conveyors, mixers, food manufacturing machines, industrial robots, crushing machines, injection moldings, and press machines. It was concluded that the absence or poor application of lockout during the non-routine work such as maintenance was one of the major causes of these accidents. However, this study does not explicitly mention the food manufacturing machines reviewed during their research (Kim et al., 2021).

Lockout is one of the methods to prevent accidents during the intervention of workers with machines. Lockout is a step-by-step procedure to ensure that any unwanted or unintentional start-up or release of energy of the machines is only possible when the lockout device is removed. In other words, when maintenance, cleaning, and adjustment are carried out, the machine remains de-energized and isolated. OSHA (29 CFR 1910.147, 1989) and Quebec's Regulation respecting Occupational Health and Safety (ROHS, 2017) have described lockout steps. Article 188.7. of Quebec's ROHS describes lockout steps as follows:

1. "Deactivation and complete shutdown of the machine;"

2. "Elimination or, if that is impossible, control of any residual or stored energy source;"
3. "Lockout of the machine's energy source cut-off points;"
4. "Verification of lockout by using one or more techniques making it possible to reach the highest level of efficiency;"
5. "Safely unlocking and reoperating the machine."

Minimum requirements for lockout steps described by OSHA's 3120 booklet are as follows:

1. Preparing the machine for the shutdown.
2. Shutting down the machine.
3. Isolation of the machine from its sources of energy.
4. Apply the lockout to the energy-isolating device(s).
5. Release all potentially hazardous stored, accumulated, or residual energy.
6. Verify if the machine is entirely isolated and de-energized.

Requirement for Lockout or control of hazardous energy on equipment and machines is defined by the American National Standards Institute (ANSI), American society of safety engineers (ASSE) (ANSI/ASSE Z244.1, 2016), and the Canadian Standards Association (CSA, 2020).

2.2.2 Definition of lockout

Lockout is a requirement for hazardous energy control (ANSI/ASSE Z244.1, 2016; CSA Z460: 20, 2020). OSHA defines lockout as "The placement of a lockout device on an energy-isolating device, by an established procedure, ensuring that the energy isolating device and the equipment being controlled cannot be operated until the lockout device is removed". Where "lockout device" is defined as "A device that utilizes a positive means such as a lock, either key or combination type, to hold an energy-isolating device in the safe position and prevent the energizing of a machine or equipment. Included are blank flanges and bolted slip blinds" (29 CFR 1910.147, 1989).

2.2.3 Laws and regulations about lockout in Quebec

Laws and regulations require companies and workers to apply energy controlling methods. The energy control method based on the subdivision of 188.1 of Quebec's Occupational Health and Safety Regulation (RSST) is defined as maintaining machinery and equipment out of all types of energies such as electrical, chemical, thermal, mechanical, hydraulic, pneumatic, and radiation in a way that unintentional and untimely energizing the machine or equipment would not be possible by other workers who might have access to the danger zone. Energy control methods prevent workers from fatal and non-fatal injuries such as cuts, burns, and electrocution. This energy control must be carried out by applying an "individually keyed" lock which is a lock designed to be unlocked with a single key. A combination of the two mentioned statements forms the definition of "lockout". In other words, applying an individually keyed lock on an energy control device in a machine or equipment is conducting lockout (The Ministère du Travail, de l'Emploi et de la Solidarité sociale, 2016).

Based on RSST law, applying lockout for every person who has access to the dangerous zone of machines is mandatory (article 188.3). Despite this, fatal and non-fatal accidents with time loss happen worldwide and in Canada every year. A comparative analysis by Chinniah showed that lockout applications are different than expected based on standards and written procedures (Chinniah et al., 2008). Some organizations consider lockout time-consuming; in many circumstances, accidents occurred, situations were assessed as usual, and as a result, the workers did not apply lockout (Wallace, 2007).

2.2.4 Lockout program

A lockout program is a written document in an organization to cover all the policies relevant to the application of lockout and control of hazardous energies.

CSA Z460 indicates the minimum content of a complete, adequate, and reliable lockout program:

- Identification of hazardous energy that is covered in the program.
- Identification of the devices for hazardous energy isolation.
- Identification of the power cut-off devices, whether installed permanently or removable.
- Selection and acquisition of protective equipment (e.g., padlocks).

- Task, duties, and responsibilities assignment.
- Determination of sequences of effective lockout steps: shutdown, de-energization (or power cut), energization, and start-up.
- Written and documented lockout procedures for machines and processes.
- Employees' training.
- Audits of the elements of the program (CSA Z460: 20, 2020).

Each organization needs to include other specifications that apply to its policy and work environment. For instance, steps that need to be followed when contractors are supposed to perform tasks on machines or when they are part of the maintaining operations such as cleaning. Moreover, the period to continue the program and the next revision expected time or modification intervals should be included in the lockout program. Also, the circumstances that the authorized person is not available and his padlock needs to be removed, must be fully covered in the lockout program. It should be noted that based on CSA Z460, an "authorized individual" is a person who is trained and has sufficient knowledge and experience to be involved in performing hazardous energy control (CSA, 2020).

2.2.5 Lockout procedure

Lockout procedures shall include the following steps in the sequence to deliver the desired result of the lockout concept, which is effective isolation of the machines and equipment from hazardous energy sources:

- Identification of the equipment, machine, or process which is supposed to be isolated from the energy source(s).
- A list containing all the devices for isolating energy sources and their locations.
- Step by step description of shutting down, isolation, blocking, securing, and releasing accumulated, stored, or residual energy.
- Step by step description of the placing and removal of lockout devices or padlocks.
- Verification requirements to assure whether isolation and de-energization have been accomplished.

- Requirements to verify that all involved personnel has evacuated the worksite (machine, equipment, or process area) and the inspection that ensures whether the machine is ready for returning to service (CSA Z460: 20, 2020).

2.2.6 Alternatives to lockout

Lockout is recommended as the primary method to control hazardous energies in ANSI/ASSE Z244.1(2016), CSA Z460 (2020), Quebec's ROHS (2017), and 29 CFR 1910.147 (1989). However, in many circumstances, there is a need to apply alternative methods. For instance, if hazardous energy needs to be present to perform the task, energy control is required to keep the machine in the safe mode. The task needs to be done frequently during the production shifts and the task is done by maintenance, operators, or set-up personnel. In these cases, alternative methods can be applied. Except for OSHA (29 CFR 1910.147, 1989), other standards require a documented risk assessment before selecting an alternative method. Conducting a risk assessment is necessary to determine whether the level of the risk after the alternative methods are reduced to an acceptable level.

Karimi et al. conducted a study on alternative methods within 14 companies in Quebec. It was indicated that only 29% of companies knew about alternative lockout methods (Karimi et al., 2019). It was concluded that the most demand for alternative methods was during the following production integral tasks (see table 2-3). Also, 10 out of 14 organizations mentioned the second reason to apply alternative methods was the need for the machine to be energized to perform the task.

Table 2-3 Number of production integral tasks that require alternative methods within 14 companies in Quebec (Karimi et al., 2019).

Reason	**number out of the 14 studied companies**
"Short duration"	11
"Relatively minor in nature"	11
"Occurred frequently during a shift or production Day"	10
"Usually performed by operators, set-up persons, and maintenance personnel"	10

Table 2-3 Number of production integral tasks that require alternative methods within 14 companies in Quebec (cont'd and end).

"Minimally interrupts the operation of the production process"	8

2.3 Food and beverage industry in Canada and The United States

The food and beverage industry is the third largest contributor to the manufacturing of gross domestic products in the United States and the second largest manufacturing industry in Canada in terms of value with production. More than 1.8 million workers are employed in the food and beverage industry in the United States (NIST, 2021; Government of Canada, 2021).

In Canada, the food and beverage industry significantly impacts on the country's economy. In 2018, this sector contributed to Canada's manufacturing revenue by 17%. Moreover, 1.7% of the gross domestic product or GDP of Canada was formed by the food and beverage industry. Furthermore, almost 19% of Canadian employment in the manufacturing sector is recorded in the food and beverage industries (Statistics Canada, 2020; Hailu, 2020; Government of Canada, 2021).

2.3.1 Hygiene and quality regulations in food and beverage industry

The food and beverage industry must meet the quality and hygiene requirements and standards that make it possible to release their products in the market. Good manufacturing practices (GMPs), Sanitation Standard Operating Procedures (SSOPs), and Hazard Analysis Critical Control Point (HACCP) are the basics for the food manufacturing industry to follow food safety standards (Demirci et al., 2020). GMPs are the minimum requirements that usually are posed by government regulatory officials. Sanitation Standard Operating Procedures (SSOPs) provide procedures for performing sanitation tasks at scheduled intervals on specific machines and equipment in the plant. The frequency can be daily, weekly, monthly, and annually or whenever the sanitation needs to be carried out on machines. SSOPs also contain the list of machines and equipment to be cleaned. Also, the cleaning procedures and methods are mentioned in SSOPs.

The Canadian Food Inspection Agency (CFIA) recommends training workers on cleaning and sanitizing procedures (CFIA, 2020). CFIA provides recommendations about the consideration of cleaning and maintenance tasks in the design of equipment, machinery, and facilities.

In the United States, the food and drug administration (FDA) requires production equipment to be designed with sanitation and hygiene cleaning considerations to facilitate the cleaning tasks. FDA also recommends having a preventive maintenance and calibration schedule (FDA, 2017).

2.3.1.1 HACCP

Hazard Analysis Critical Control Point (HACCP) is an effective means to guarantee food safety from the harvesting process to the hands of customers and consumers. It was developed for the USA army and NASA with the goal of zero defects in food products (Bolat, 2007; HACCP Principles and Application Guidelines, 2017). Over the years, HACCP has become mandatory in different sections of the food and beverage industry in the United States, Canada, and European countries. United States Department of Agriculture (USDA) required all large, medium, and small size plants to implement HACCP by 1998, 1999, and 2000, respectively (Demirci et al., 2020). In Canada, the quality management program which required HACCP to be implemented in the food and beverage industry (fish processing facilities) was established in 1992 (CFIA, 2020).

To verify HACCP, food safety inspections rely on preventive measures and in-process controls. HACCP is implemented in Canada after performing a documented prerequisite program that tries to minimize the critical control points or CCPs; CCPs are points in the process that inadequate control could lead to major food health or food safety risks (Nguyen et al., 2004). The prerequisite program for HACCP in Canada comprises six elements: “premises, transportation and storage, equipment, training, sanitation and pest control, and recalls.” Each element focuses on one section from harvest, food production, consumption, possible hazards, and recalls. Production machines and equipment design, manufacturing, installation, and preventive maintenance satisfy the equipment element. Training element provides training programs that include food hygiene, cleanliness and cleaning, technical issues, and contagious diseases (Nguyen et al., 2004). In contrast, implementation of the HACCP methodology usually leads to increased occupational risks to workers, as cleanings and elimination of contaminations are more in demand than in other industries (Jacinto et al., 2009).

2.3.2 Cleaning operations in the food and beverage industry

As mentioned above, implementing HACCP in the food and beverage industry requires cleaning machines, equipment, and the work area. The cleaning and sanitation process in the food and beverage industry needs to be done with specific tools and equipment and usually in abnormal environments such as confined spaces, extreme heat, or cold and slippery floors, which cause risks and fatigue. For instance, sanitization standard operating procedures (SSOPs) require workers to use high-pressure and heavy hoses, water nozzles, shovels, brushes, scouring pads, and portable foam makers in temperatures higher or lower than usual. Moreover, workers must wear safety helmets, hair and beard net, chemical resistant gloves and sleeves, water-resistant suits, and chemical-resistant steel toe shoes (Demirci et al., 2020). Furthermore, in many cases, cleaning operations in the food and beverage industry for HACCP purposes involves entering confined spaces, such as tanks and cyclones (Bolat, 2007). Inhaling dust and particles is another contributing factor during cleaning operations. For instance, the filling process in beverage production plants requires extremely clean air, which is solved by installing high-efficiency particulate air (HEPA) filters. These filters need regular maintenance and cleaning for efficiency and hygiene regulations (Manfredi & Vignali, 2015). However, cleaning and replacing filters can expose workers to inhaling particles (Mazzuckelli et al., 2007).

2.3.2.1 Dry and wet cleaning

Food processing plants widely utilize transport equipment such as conveyors, pumps, and compressors as they deal with solids such as powders, liquids with different densities such as milk, syrups, and gases such as vapor and filtered air, respectively. This equipment should be designed to be easily drained and cleaned (Demirci et al., 2020). A type of cleaning in the food and beverage industry is dry cleaning, without using liquids on equipment such as electrical panels and motors. It is usually performed by vacuuming and high-pressure air blowing. Dry cleaning also can be used as a step before wet cleaning. Wet cleaning is used for cleaning surfaces such as pipes and vessels that exposure to water does not affect their functionality. This type of cleaning is usually performed using hot water, sanitation chemicals, decontamination fluids, high-pressure nozzles, and hoses.

2.3.2.2 Cleaning in place (CIP)

In addition to cleaning and sanitization by hand or manually, automated cleaning methods are suitable for food and beverage industries where applicable. CIP (cleaning in place), or the cleaning system for surfaces inside pipelines, mixers, tanks, vessels, and pumps, is an automated method. CIP reduces the time consumed for cleaning operations, as well as reduction of the exposure time of operators with sanitizers and decontamination fluids. Also, the need for dismantling parts of equipment and machines decreases dramatically, depending on the level of automation of the CIP system. For instance, the necessity of working in close contact with blades or agitators inside the mixer will be omitted as cleaning is derived from the circulation of sanitizers through mixers and downstream vessels (Thomas & Sathian, 2014). In food and beverage processing plants with high productivity and complex production equipment, automated cleaning methods such as CIP are desired. Performing CIP increases the productivity and efficiency of food and beverage production plants. For instance, evaporators are used in plants dealing with liquid food products due to their high efficiency. Complex piping and utilizing various pumps, vents, and confined spaces are inherent in evaporation processes. In evaporators, liquid foods become more viscous as the existing water evaporates; therefore, maintaining evaporators needs automated sanitization and cleaning (Demirci et al., 2020).

2.4 Maintenance in the food and beverage industry

In addition to the rigorous cleaning requirements, frequent maintenance of machines and equipment is needed to reduce the possibility of contamination in the facility. Performing planned or unplanned maintenance is a task that usually requires workers to work in dangerous environments such as close to moving parts of machines. Cleaning, lubrication, and inspection are the tasks that usually occur during maintenance activities.

A significant number of occupations are involved in maintenance activities. For instance, based on the French Association of Engineers and Maintenance Managers (AFIM), 420000 jobs are directly related to maintenance operations in France. Maintenance workers are exposed to more accidents and occupational diseases than other professions. According to CNAMTS, (National health insurance fund for salaried workers of France or Caisse Nationale d'Assurance Maladie des travailleurs salaries), in 2015, maintenance workers were involved in fatal accidents 3.35 times more than the national average (Blaise J.C. et al., 2017).

There are different types of losses in manufacturing industries. Decreasing these losses can improve the reliability and reduce the unplanned stoppages, which can result in reduction of maintenance and intervention activities. Previous research studies have categorized losses in machines in six categories (Nakajima, 1988; Chan et al., 2005):

- Breakdown losses,
- Set up and adjust losses,
- Idling and minor stoppage losses,
- Reduced speed losses,
- Quality defects and rework losses and
- Start-up losses.

Any of these losses can cause interventions of operators and workers with machines for cleaning and maintenance purposes. Also, cleaning is an inherent step of setup and adjustment losses.

2.5 Accident statistics

In provinces of Canada, there are different occupational health and safety legislation and workers' compensation boards. Websites of CNESST, WorkSafeBC, WSIB, and WCB were reviewed for data collection in Quebec, British Colombia, Ontario, and Alberta, respectively. The other compensation boards were excluded because there was insufficient data relevant to this study in other provinces.

There are classification codes for each section of the industry. However, different provinces follow different North American Industry Classification System (NAICS) or food and beverage industry classification codes. For instance, in CNESST, 311 and 312, and in WorkSafeBC, 7110 are assigned to this industry. These websites provide detailed fatal accident investigation reports; however, few reports were available for serious and minor accidents.

Tables 2-4 and 2-5 provide information about the number of non-fatal and fatal accidents in the food and beverage industry across Canada, respectively. The number of non-fatal incidents has increased overall. The share percentage among all industries within a province has remained almost steady. This indicates growth in several active industries, production rates, and the increase of non-fatal incidents in all industry sectors. It should be noted that, although the number of incidents in Alberta is relatively lower than in other provinces, its share percentage among industries within Alberta is higher than in other provinces. For instance, if safety in Alberta's food and beverage industry is improved, approximately 9% of all the non-fatal incidents decrease, and 9% of work environments become safer. These accidents occurred by different causes. For instance, two of four fatal accidents in British Columbia in 2016 were due to falling down the stairs. One fatality occurred due to the inhalation of fire smoke in a building, and the other one occurred due to a truck rollover. The following two tables indicate that the food and beverage industries are among the sections with high incidents and accidents. Therefore, attention to safety improvements in this sector should be of great importance.

Table 2-4 Non-fatal accidents occurred in food and beverage industry in Quebec, British Columbia, Ontario, and Alberta (www.cnesst.gouv.qc.ca, www.worksafebc.com, www.wsib.ca, www.wcb.ab.ca).

Province / Year	**2019**	**2018**	**2017**	**2016**	**2015**
Quebec	4613 (5%)	4514 (5%)	NA	NA	NA
British Columbia	1408	1335	1293	1236	NA
Ontario	1234 (3%)	1259 (3%)	1122 (3%)	1120 (3%)	1023 (3%)
Alberta	514 (9%)	586 (10%)	504 (9%)	NA	NA

Table 2-5 Fatal accidents occurred in food and beverage industry in Quebec, British Columbia, Ontario, and Alberta (www.cnesst.gouv.qc.ca, www.worksafebc.com, www.wsib.ca, www.wcb.ab.ca).

Province / Year	2019	2018	2017	2016	2015
Quebec	2	1	NA	NA	NA
British Columbia	0	0	0	4	NA
Ontario	0	0	0	1	1
Alberta	0	0	0	NA	NA

Table 2-6 provides a few accident summaries to illustrate how unsafe working methods lead to death or injuries. In addition to these accident investigation reports, other investigations have been studied, which provides a better understanding of the situations to develop a complete checklist. Table 2-7 includes accident summaries from industry sectors other than food and beverage. Although these accidents occurred in different sectors, they illustrate the common unsafe working conditions and procedures that lead to fatal or serious accidents.

Table 2-6 Summary of Canada's food and beverage industry accidents in Quebec, British Columbia, and Ontario (www.cnesst.gouv.qc.ca, www.worksafebc.com, www.wsib.ca).

Province	**Year**	**Incident Summary**
Ontario	2016	A worker suffered from fatal injuries when he was caught in a cheese cutter machine.
Quebec	2020	A worker died while cleaning the screw in a dryer silo. No lockout was applied.
Quebec	2020	A worker fell from a hole in the ceiling when installing new equipment.
Quebec	2016	A worker was dragged and trapped by moving parts while he intervened in the hopper of a meat grinder. He was seriously injured.

Table 2-6 Summary of Canada's food and beverage industry accidents in Quebec, British Columbia, and Ontario (cont'd and end).

Quebec	2019	A worker prepared to clean production line 2 using a high-velocity pump. As he pressed his hands on the pump to close the valve, he was electrocuted and died.
Quebec	2013	A foreman inspected a gearbox, the engine started to work, and he was trapped and died.
Quebec	2003	While cleaning and unblocking a sorting machine, a worker's arm was amputated.
Quebec	2000	A worker cleaning the conveyor during the night shift died. The conveyor suddenly started, and he was caught in.
British Columbia	2017-21	The worker's thumb was crushed while troubleshooting a pallet wrapping machine. The lockout application was inadequate.

Table 2-7 Summary of accidents in sectors other than food and beverage industry in Quebec, British Columbia, Ontario, and Alberta (www.cnesst.gouv.qc.ca, www.worksafebc.com, www.wsib.ca, www.wcb.ab.ca).

Province	**Year**	**Industry**	**Incident summary**
British Columbia	2015	Sawmill	An energized stacker moved towards a worker while performing maintenance and he died.
British Columbia	2015	Recycling company	A worker tried to unjam a conveyor without applying lockout, the conveyor's motor suddenly turned on and his arm was severely injured.
British Columbia	2014	Planer mill	A worker was severely injured while performing maintenance on series of equipment. Only one of the equipment was locked out.
British Columbia	2013	Sawmill	A worker died while cleaning a conveyor, which was not locked out.
Ontario	2018	NA	While removing material from a machine, a worker died as part of the machine moved.
Ontario	2017	NA	A worker died after being caught between two machines.
Ontario	2017	NA	A worker died while performing cleaning on a concrete mixing machine.

Table 2-7 Summary of accidents in sectors other than food and beverage industry in Quebec, British Columbia, Ontario, and Alberta (cont'd and end).

Quebec	2019	Animal breeding	A worker entered a scrubber to search for the cause of noise and perform cleaning. The scrubber started to operate, and he was caught in and died.
Alberta	2018	Manufacturing	The plant manager entered a mixing hopper that was not locked out. Mixer suddenly activated and he was pinned between the wall and agitator. He died.

Based on the Workers' Compensation Board of British Columbia or WorkSafeBC, 7014 total time-loss claims were recorded in the food and beverage industry between 2017 to 2021. 785 (11%) loss time accidents occurred in the food and beverage industry in British Columbia, were caused directly by machines. Figure 2-1 illustrates different accidents within British Columbia; "caught in" is one of the most common types of accidents in the food and beverage industry between 2017 and 2021. WorkSafeBC defines caught-in as "cases where the injury resulted from the squeezing, crushing, pinching that took place once contact with the object had started". "Struck by" accidents are defined as " where the motion producing the contact was primarily that of the object or source of the injury". In "struck against" accidents, the motion that produces the hazardous contact or source of injury is provided by the injured individual. "Overexertion" accidents occur in cases where workers use body force on objects, and "falls on the same level" are accidents where the person was injured due to slips, trips, and falls (falls from only a few inches higher than the floor are in this category).

The accident statistics from the compensation boards in four provinces of Canada were reviewed (Quebec, British Columbia, Ontario, and Alberta) . However, the accident investigations reports were completely available for the province of Quebec which are used in this research study as an important resource. Machinery safety and lockout as a safeguarding method are reviewed in this chapter. Furthermore, the importance of the food and beverage industry in Canada, the hygienic regulations and standards, and different types of cleaning and hygienic methods in the food and beverage industry were studied. Moreover, the influence of the food and beverage industry on the economy, the number of employed individuals in this sector, the complexity of cleaning tasks, and the high number of accidents, indicate the importance of conducting this research study. In the next chapter, the research gap, objectives, and methodology will be explained. Accident statistics and investigation summaries in the food and beverage industry showed a gap between the current situation and the zero accident targets. Despite the existing regulations and methods provided for safe operations of facilities, these accidents occur. Therefore, it is necessary to conduct more studies to identify the root causes to minimize the possibility of these accidents.

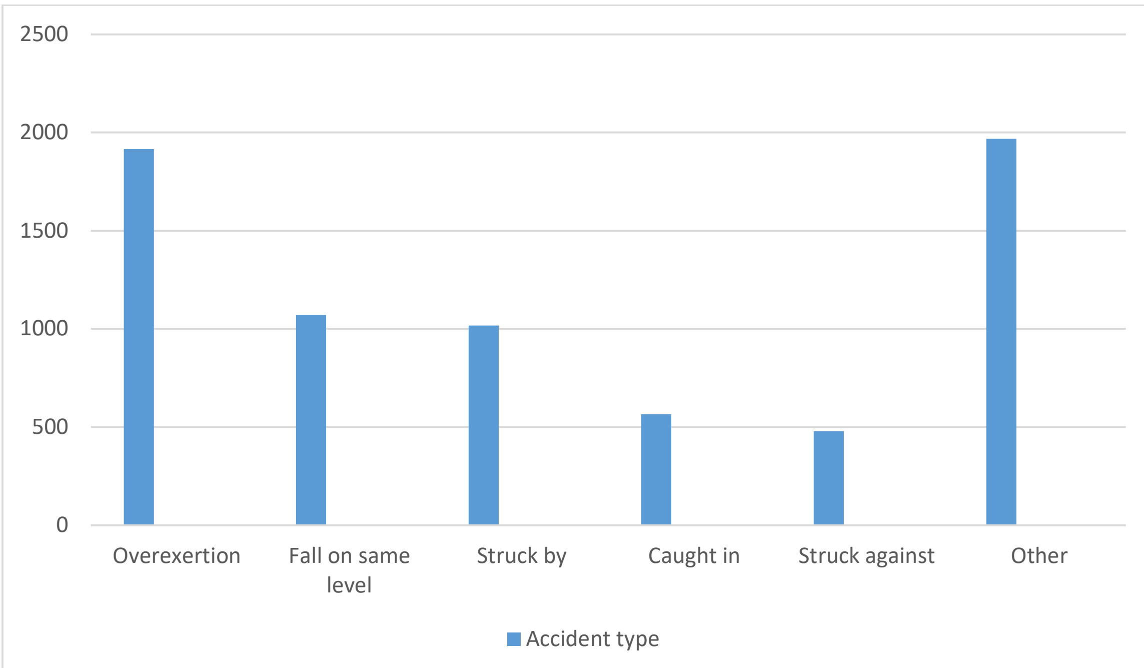

Figure 2-1 Occurrence of different accident types in food and beverage industry in British Columbia between 2017- 2021 (WorkSafeBC, 2022).

CHAPTER 3 OBJECTIVES AND METHODOLOGY

3.1 Research gap

Based on the literature review, many fatal and serious accidents in the manufacturing industry occur during non-routine operations. The food and beverage industry has been operational worldwide and across Canada for decades and forms one of the country's most significant shares of GDP. This industry sector relies heavily on complex machines, equipment, and processes. The food and beverage industry must meet rigorous quality and hygiene requirements. Therefore, cleaning various machines, equipment, tools, and work environments is needed. Planned and unplanned cleaning operations are one of the major non-routine operations in the food and beverage industry due to the strict hygiene regulations. Workers perform cleaning close to dangerous zones of machines, near moving parts, inside vessels, and mixers with challenging work conditions such as slippery surfaces, hot surfaces, hot water, carrying heavy hoses, reduced visibility due to masks, vapor, goggles, hair and beard net. To minimize the risk of different types of hazards such as moving parts of machinery and electricity while performing cleaning tasks, occupational health and safety codes and standards require workers to follow safe work methods and procedures such as risk assessments and application of lockout (or lockout alternatives) as means of energy isolation before the start of the job. Although such risk reduction measures are mandatory, accidents still occur during intervention with machines and equipment. Therefore, it is assumed that there is a gap in the proper and complete application of all safety procedures and practices during non-routine work in the food and beverage industry. This research aims to identify the obstacles to preventing accidents in the food and beverage industry when performing non-routine work, with more focus on cleaning. Furthermore, it is desired to present an assessment tool and recommend solutions to improve safety in the workplace.

3.2 Research objectives

The main objective of this research is to identify the main causes and the contributing factors leading to serious injuries and fatal accidents while performing cleaning operations in the food and beverage industry as well as proposing solutions and recommendations. The specific objectives are:

- To identify the barriers and obstacles in performing the tasks safely in the food and beverage industry.
- To review accident investigation reports to identify main causes and contributing factors to the accidents and risk reduction measures in terms of individual, organizational and technical in the food and beverage industry.
- To recommend solutions to improve the safety of the workplace.
- To provide a checklist based on the identified factors as an assessment tool.

Achieving these objectives will fill the gap in the identification of contributing factors in the accidents related to cleaning in the food and beverage industry and provide solutions to overcome this issue. Furthermore, a comprehensive database including contributing factors to the accidents, risk reduction measures and accident investigation reports, will be provided based on this research.

3.3 Methodology

To achieve these objectives, the methodology is presented in the following steps:

3.3.1 Literature-based causes and contributing factors to accidents in food and beverage industry

During the first step, the requirements, such as codes, legislations and standards, relevant studies, and books were reviewed and studied. This part was done with a focus on accidents in the food and beverage industry. The following keywords and their combinations were used for searching the scientific databases (such as Compendex and Google Scholar):

- Food and beverage: Other keywords such as “food industry”, “food manufacturing”, “food and drink industry”, “beverage industry”, “beverage industry” and “drink manufacturing” have been included.
- Cleaning: Other keywords such as “sanitation” or “sanitization” have been included in the search.
- Accidents: “Incidents” and “fatal and serious accidents” were included.
- Occupational safety: Other similar keywords such as “OHS”, “health and safety”, “risks”, and “hazards” were included in the search.

- Hygiene and quality requirements in the food and beverage industry were included.

It should be noted that papers relevant to the term "food safety" were excluded as they are from biological, food poisoning, and quality control points of view, which were irrelevant to this research.

Then, all the documents, including journal papers, research projects, and conference papers were imported to Endnote to organize the referencing and citation process.

3.3.2 Accident reports

To review the details of the accidents in the food and beverage industry across Quebec, the Workers' compensation board and occupational health and safety regulatory organization in this province (CNESST), were reviewed. Regardless of the type of activities performed during the accident, they were reviewed. In the next step, causes, contributing factors, and risk reduction measures were categorized into groups of "individual", "organizational" and "technical". This classification made it possible to understand the situation and provide beneficial recommendations. It should be mentioned that only accidents with fatal or serious consequences were studied.

Reviewing the accident reports, and the review of research papers in the previous step, provided causes, contributing factors, and risk reduction measures that lead to the accidents.

3.3.3 Checklist

In the next step, a checklist was proposed to help the users assess the level of safety in the workplace. Identified factors from the literature review were included to present a comprehensive and practical checklist. Therefore, identified direct causes, contributing factors, and risk reduction measures were used to form the checklist. Moreover, some of the research studies from IRSST that proposed checklists were reviewed. The checklist was formed of different statements that can help in hazard identification of the workplace as well as identification of the areas that can be improved.

3.3.4 Case study

Due to the restrictions caused by the Covid-19 pandemic, using the checklist to assess its effectiveness and implement recommendations on an industrial scale was not possible. Therefore, a scenario-based approach was chosen to verify the proposed checklist's effectiveness. To illustrate the implementation of the checklist, one accident report was used as a sample to perform a scenario-based assessment. When the scenario-based case study was conducted, meetings with professors were held and the level of effectiveness of the checklist was assessed. As a result of these meetings, more statements were added or modified for further development of the checklist.

3.3.5 Recommended good practices and solutions

Based on reviewing scientific papers and the accident reports, good practices, and solutions to minimize the potential causes and contributing factors were identified. These recommendations were presented as means of safety improvement in the workplace. Furthermore, the good practices from other industry sectors adapted to the food and beverage industry were shown.

CHAPTER 4 RESULTS AND DISCUSSION

The direct causes of the accidents can be one or more items. However, other hidden factors can usually cause the final event. These causes and contributing factors are usually identified after the accident occurrence, during the accident investigation process. In this research, identifying these factors played an essential role in preparing the comprehensive and practical checklist. When the review of the scientific databases was conducted, the contributing factors to the accidents in the food and beverage industry were identified.

4.1 Results

The identified contributing factors to the accidents from the scientific databases are presented below. Factors are categorized into three groups of individual, organizational, and technical. However, in some cases, these factors can fall under more than one category and are not completely separated.

4.1.1 Literature-based causes and contributing factors to the accidents

Table 4-1 indicates the causes and contributing factors and summarizes the essential details about the accidents in the food and beverage industry around the world. These factors resulted from the review of scientific papers and books. Cleaning and maintenance of machines and equipment were the activities that were mentioned the most in the literature. The collected references covered developed and developing countries.

Table 4-1 Summary of the occupational accidents in food and beverage industry.

Accident type / location / reference	**Activity**	**Machine/ Equipment**	**Causes / contributing factors**		
			Individual	**Organizational**	**Technical**
Multiple hand injuries/ Sweden/ (Stave & Törner, 2007)	Cleaning/ Maintenance	-	-	Lack of communication/ lack of training/ production pressure/ unclear working method/ hygiene demand.	Machine downtime/ design of machine without consideration of cleaning and maintenance/ hot, slippery environment/ heavy tools for hygienic requirement.
Fire/ Italy/ (Landucci et al., 2014)	Cleaning/ maintenance	Packed column (edible oil refinery)	-	Out of date risk assessments.	Equipment was designed without considering cleaning and maintenance operations/ severe process conditions.
Multiple accidents/ Italy/ (Comberti et al., 2018)	-	-	-	Size of company (larger companies can reduce accidents better).	-

Table 4-1 Summary of the occupational accidents in food and beverage industry (cont'd).

Multiple accidents/ Ghana/ (Quartey, 2017)	-	-	Lack of job satisfaction .	Poor organizational leadership in safety behavior.	-
Multiple factories were studied/ Nigeria/ (Otitolaiye et al., 2019)	-	-	-	Lack of safety culture (at all levels) increases risks and accidents.	-
Multiple accidents/ France/ (Giraud et al., 2018)	Cleaning	-	-	Night and weekend shifts (Saturdays).	
Multiple causes in wineries / Spain/ (Anaya-Aguilar et al., 2018)	Production/ storage/ machine operation	-	-	Unsafe storage method/ the use of the same path for workers and moving pallets/ wet surfaces after cleaning/ slips, trips, and falls/ electric current/ lack of emergency training/ lack of supervision	Removed guards and protective devices/ intervention with machines in the operating mode

Table 4-1 Summary of the occupational accidents in food and beverage industry (cont'd and end).

Multiple fatal and serious accidents/ UK/ (HSE UK, 2005)	Maintenance/ Cleaning/ loading unloading/ work at height/ objects falling from height/ struck by heavy machinery.	Robotic palletizer machine/ conveyor/ moving parts/ storage tank/ silo/ trucks/ trailers/ heavy machinery.	The driver forgot to apply the truck's brakes.	Absence of lockout program/ lack of safety culture/ poor health and safety management/ lack of routine maintenance/ history of accidents without corrective actions/ lack of communication/ lack of safe working methods/ lack of training/ lack of suitable emergency response procedures.	Absence of lockout/ absence of gas test/ poor design of silo for cleaning operations/ removed guards.

Based on the literature review presented in table 4-1, the contributing factors to the accidents that occurred during non-routine activities such as cleaning and maintenance were identified. Furthermore, a few pieces of literature from other manufacturing industry sectors were summarized. They were not excluded from the review, as the machines, contributing factors, and methods were common in the food and beverage industry. The summary of these factors was categorized under the following 6 groups. These categories were selected based on the most common causes and contributing factors to the accidents in the literature review:

- Poor design of equipment or machines
- Productivity pressure
- Training of workers

- Safety culture
- Accident underreporting
- Deficient health and safety management

These factors are discussed in more detail in the following section.

4.1.2 Discussion on the literature-based causes and contributing factors

Based on the results of the review of scientific papers, there are usually different factors that can cause accidents. Factors such as the absence of lockout, accessible dangerous zones, and removed guards, have been topics of different studies in machinery safety for years (Kim et al., 2021; Karimi et al., 2019; Haghighi et al., 2019; HSE UK, 2005). The lack of lockout is a crucial factor in the occurrence of machinery related accidents. Such accidents can occur due to individual, organizational and technical issues. The reason to categorize contributing factors into the three mentioned groups is the root causes of accidents. When individuals are directly involved in the occurrence of an accident, they will be categorized as individuals or human error. For example, when a driver forgot to follow the procedure or when an operator intentionally bypassed a safeguard, individual contributing factors lead to the accident. When there is poor safety management or lack of safety culture in an organization, organizational contributing factors caused the occurrence of the accident. Furthermore, in cases the design of machines or layout of the equipment was poor, the technical category contributes to the accidents. To illustrate these three categories, more examples are provided. For instance, the literature review indicated that the training for lockout was insufficient, or the scope of the lockout program did not cover different tasks such as cleaning, and accidents occurred. Furthermore, there were circumstances where the guards were removed or were not installed, and as a result, dangerous zones of machines were accessible. However, other contributing factors were reviewed in fewer studies. For instance, few studies mentioned accidents due to lack of staff, hiring seasonal workers, or performing the cleaning during night and weekend shifts. Cleaning tasks are usually done during night and weekend shifts. That is due to the less productivity pressure and more time for workers to perform their tasks. However, during these shifts, there is usually less supervision and support from their supervisors or certified personnel. Some important organizational factors were lack of training and communication for specific tasks such as cleaning or maintenance, unclear or unsafe working methods, obsolete risk assessments, pressure from productivity, and hygiene demand. Moreover, few studies concluded that larger companies are more likely to reduce risks than smaller companies. The improper design of machines and equipment was a crucial contributing factor to the accidents. In several cases, machines were designed and manufactured without consideration of cleaning and maintenance tasks. As a result, safe access to different parts or safe entry to machines to perform such tasks was impossible. The organization's safety culture, at all levels, from managers and leaders to operators, was mentioned as one of the most important contributing factors to the accidents.

In the following sections, productivity, underreporting, equipment design, training, safety culture, and poor safety management are reviewed and discussed in more detail.

4.1.2.1 Productivity pressure

Production schedules and targets in the food and beverage industry can cause pressure on the workers. The changeover of different products, the seasonal demand, and the hygiene requirements, pose productivity pressure to the operators in performing their tasks. Numerous accidents and injuries are left without being reported to the supervisors. Production pressure can cause accidents and underreporting of accidents by workers (Probst & Graso, 2013). Moreover, another research by Probst indicated that workers tend to choose productivity over safety when there is the possibility of being laid off and downsized (Probst, 2002). In organizations where growth and production efficiency is their only priority, the occurrence of fatal occupational accidents and diseases is inevitable (Kim et al., 2021). Another study considers productivity pressure and lack of time to meet customer needs as the main reasons to violate safety procedures than can cause accidents. Furthermore, lack of employee awareness and training about protective devices and procedures, and inadequate skills relevant to a specific machine, equipment, or process are categorized as types of production pressure (Hopkinson, J., Lekka, 2013). A study in the U.S. showed that productivity pressure and cost effectiveness from organizations and supervisors cause workers to work faster and sometimes neglect safety procedures (Leveson, 2004). Furthermore, the absence of proper maintenance plans can cause numerous downtimes of machines and production lines (Stave & Törner, 2007).

4.1.2.2 Underreporting of the accidents

There are two types of organizational and individual underreporting. Organizational underreporting happens when an organization does not report accidents and injuries to regulators. Individual accident underreporting happens when employees neglect to report workplace injuries to their supervisors and employers. Both types of underreporting can cause serious problems. Individual underreporting usually causes untreated injuries. Moreover, employees' assessment of the root causes of the accidents might remain incomplete, fruitless, and unfixed which might cause accidents in the future. Organizational underreporting causes statistics of the national legislators to remain inaccurate (Petitta et al., 2017). Even though the public might think fake accident reporting rates are high for compensation purposes, underreporting is more widespread; studies estimate that almost 80% of workplace accidents remain unreported (Probst & Graso, 2013; Probst et al., 2008).

4.1.2.3 Poor design of the equipment and machines

A major accident in a vegetable oil refinery occurred due to the accumulation of residues inside the packed column. The accident happened during cleaning operations (Landucci et al., 2014). Further investigations showed that the packed tower design made the cleaning operation too difficult and time-consuming as the packings inside the tower were impossible to be removed. Non-routine procedures such as cleaning should not be assumed as simple and risk-free tasks. Cleaning should be considered in the design stage of machines, equipment, and processes. For instance, columns with flanged ends are the desired design as the packing structures can be removed for cleaning with less time. After the investigations were completed in the refinery, it was recommended that all risk and hazards assessment, evaluation forms, and procedures should be reviewed regularly and updated if needed (Landucci et al., 2014).

Machines, in some cases, are designed only for productivity targets. Therefore, safety issues such as ergonomics, minimization of the need for human intervention with machines, noise, and vibration controls are neglected. Maintenance considerations in the machines and equipment design phase mean all machines' operating modes and working methods must be predicted and considered. Machines and equipment designed for the food and beverage industry, require access to load or unload materials, cleaning, adjustment, unjamming, and fault findings. The inner side of machines should be designed to be cleanable without the need for entry. Also, the design of control panels, layout of machines, and location of on and off buttons play an essential role in the better design of machines to minimize the possibility of remote activations of machines (Bulzacchelli et al., 2008).

The French National Research and Safety Institute for the Prevention of Occupational Accidents and Diseases (INRS) recommends 9 criteria to be considered in the design stage:

- “Access and processing of information”: Any type of information transfer and communication between machine and human by signals, symbols, diagrams, and words must be accessible to the point that the maintenance operation is supposed to be performed. This will help workers perform their tasks without any confusion jeopardizing their safety.
- “Accessibility”: The possibility of reaching the necessary points without many constraints is important. Proper accessibility reduces the time spent on maintaining activities and poor ergonomic postures. Also, it is mainly desired to design access points outside dangerous machines.
- “Diagnosis aid”: Helps workers to realize the failure before undertaking intervention with the machines. Moreover, diagnosis aid improves preventive maintenance by predicting future losses. It is vital to consider remote starting or re-starting, and remote lockout in case of remote diagnosis design in the machine.
- “Physical work environment”: Considering noise, heat, cold, light, and vibration in the design phase can improve the non-routine tasks such as cleaning, lubricating, and troubleshooting. This will provide more efficiency, less disturbance and better communication between the team.
- “Lockout”: Machines must be designed with devices to provide the opportunity to be locked out of all their energy sources. After applying lockout and energy isolations, machines and equipment should be designed to release all residual energies without putting operators at risk.
- “Technical documentation”: It is the technical manual of all phases of the machines, such as assembly and installations, commissioning, operator training, protective measures such as PPEs, maintenance, and adjustment. Also, diagrams of pipelines and electrical systems must be provided for safe maintenance.

- "Specific maintenance operating mode": An operative mode designed for maintenance tasks in the hazardous area with removed guards must be designed. The design must ensure that deactivation of all other commands, implementation of functions only in reduced dangerous mode, and prevention of unintentional or intentional actions of machine sensors are achieved. Also, this maintenance option must only be available for the devices that require such maintenance, and not on every single part of the machine or equipment.
- "Positioning of maintenance points": Machines should be designed to minimize the ergonomic risks for maintenance workers. Also, positioning adjustment and maintenance points that are out of dangerous zones, can increase productivity.
- "Hydraulic and pneumatic equipment - Prevention of dangerous phenomena.": INRS mentions that hydraulic and pneumatic energies are widely used with a pressure range of a few bars to several thousand bars, which should be designed to prevent untimely release and expose hazards to workers. Lockout, positioning of maintenance points out of the hazardous area, and assuring safe release of energy before the start of the non-routine tasks can prevent accidents (INRS, 2010).

4.1.2.4 Training of workers

Inadequate training is another important contributing factor to the accidents. Therefore, providing proper and sufficient training for workers is a risk reduction measure. During the safer maintenance campaign held by the European agency for health and safety at work, it was mentioned that it is crucial to consider maintenance activities as a complex process rather than a simple task. Therefore, such activities need sufficient training to ensure that the workers performing maintenance jobs are trained and competent (INRS, 2017). Previous research studies have introduced training as a vital factor and solution to the problem of bypassing safety procedures and devices (Haghighi et al., 2019; Hopkinson, J., Lekka, 2013). Training is essential to provide workers knowledge and improve their expertise to face residual risks of machines, equipment, and processes. Moreover, a deep understanding of existing hazards in the work environment will make it possible for workers to follow and respect safe and preventive working methods, reducing accidents and injuries (Robson et al., 2012). Training plays an important role in preventing accidents, but the length of training is also important. Training an operator to handle simple equipment needs a shorter time than complicated equipment or a system that needs a long training period for workers to understand it thoroughly (Kim et al., 2021). Canadian and Quebec legislations require special training for workers authorized to apply alternative methods in lockout (Karimi et al., 2019). ISO 12100(2010) categorizes safe working procedures, supervision, permit to work systems, personal protective equipment, and training as protective measures that need to be carried out by machine users. It should be noted that among these mentioned protective measures, training has a direct impact on all others (CSA Z432-04, R2014). Training needs to be regularly refreshed to keep the employees up to date and have the most efficiency in implementing safety practices. While intervals between training cannot exceed 3 years, it is important to record and document the training history of workers (Karimi et al., 2019; Demirkesen & Arditi, 2015; Stave & Törner, 2007).

4.1.2.5 Safety culture

Safety culture is the commitment of workers of a company or an organization at all levels to that organization's established safety programs and procedures. It is safe to say that the safety culture is at a high level if operators do all their tasks based on their safety procedures and regulations, even without their supervisors or managers (Antonsen, 2009) and (Strauch, 2015).

The main assumption of the research projects on safety culture is a relationship between safety and organizational culture. In sociology, culture is the value that is the norm between members of a society (Antonsen, 2009). Antonsen believes that organizational culture applies to informal aspects of an organization. The safety culture was first used in the accident investigation reports of the Chernobyl disaster. Studies on safety culture for decades have shown that cultural traits and level of safety in an organization are connected, and the correlation between "planners" of a safety program and "doers" of that program, actually forms the power (Antonsen, 2009).

Numerous models are available to assess human factors in accidents and analyze causes of human errors, such as STAMP (Systems Theoretic Accident Model and Processes) developed by Leveson and Reason's Swiss Cheese Model. Nonetheless, human behavior varies in different situations and people might react differently to the same issue. Therefore, organizational studies can lead to a better understanding of the root causes of accidents (Rao, 2007).

Baram believes that in-depth interviews can reveal the actual level of safety culture (Baram & Schoebel, 2007). Although assessment of organizational factors such as procedural compliance might present a proper safety situation, they cannot be considered reliable evidence to assure the prevention of accidents is guaranteed; But, this type of assessment can help the supervisors the establishment of safe operational practices and could be an indicator of organization safety culture (Strauch, 2015). Also, in some cases, investments in improvements to cultural safety might tempt managers to reduce financial support and invest less in technical safety and inherently safe design of equipment and machines (Baram & Schoebel, 2007). Employees' safety behaviors are highly affected by organizational leadership and job satisfaction (Quartey, 2017). Therefore, pressure from organizations, managers, and supervisors who put productivity and cost-effectiveness in higher priority than safety, would cause workers to adapt themselves to degenerated and weakened safety systems over time. In other words, in these situations, workers tend to change their work environment and neglect the safety systems and procedures to achieve their goal of more productivity in a shorter time, which is called adaptation (Leveson, 2004).

After the Piper Alpha disaster in 1987, attention was dragged to improve the existing safety systems called "safety management systems". Vierendeels presents three safety dimensions. Two of them are already mentioned above; technical and engineering as first, and rules and enforcement as the second dimension. Vierendeels introduces education and knowledge improvement as the third dimension (Vierendeels et al., 2018). This is called the "3E's model" by the National Safety Council which is formed of engineering, enforcement, and education. The effectiveness of safety education is evidenced by safer workplaces and companies. Communication between different levels and showing that everyone should be informed about safety matters can enhance organizational safety. Oral safety training and communications, walk the talk, and discussion and presentation of safety statistics of the company would increase the sense of being informed. It should be noted that in all the mentioned items, quality should be the priority over quantity. For instance, high-quality oral training can be more effective than several mediocre training. There are three dimensions of occupational safety that have correlations with each other. The technological, organizational, and personal psychological domains influence technical factors, degree of safety perception, and behavioral motivation, respectively (Vierendeels et al., 2018). Another research by Moreno on risk awareness and safety culture suggests that a specific reporting system is necessary for complete and detailed accident investigation and reports to enhance of safety barriers and systems (Moreno & Cozzani, 2015). Positive safety culture lies in management levels and their care and commitment to workers and safety. This benefits the better understanding and knowledge of organizational hazards which will result in better risk and hazard control (Otitolaiye et al., 2019). As accident underreporting is another noteworthy issue, research surprisingly concluded that safety culture does not impact accident reporting directly; in fact, safety culture shapes and improves safety-related moral disengagement of employees, which could affect all aspects of workplace safety enhancement (Petitta et al., 2017).

4.1.2.6 Deficient health and safety management

Lack of supervision and management from the health and safety committee has been identified as one of the most important contributing factors to accidents in the workplace. The existence of obsolete and out of date safety procedures, operating procedures, lockout programs, and risk assessments, fall under this category (Leveson, 2004; Landucci et al., 2014, Stave & Törner, 2007). Also, the lack of a proper job hazard analysis for specific tasks such as cleaning can cause accidents (HSE UK, 2005). Furthermore, selecting the appropriate tools for the tasks, such as long handles for cleaning inside the mixers, can reduce the risks to the workers. Recommendations on purchasing appropriate personal protective equipment (PPE) such as boots and gloves, with consideration of the work environment, while performing cleaning, such as slippery surfaces, can help prevention of accidents. Another important risk reduction measure is supervising cleaning and maintenance tasks in the food and beverage industry that usually takes place during night or weekend shifts. Moreover, cleaning and maintenance tasks in the food and beverage industry usually occur during the night or weekend shifts (Giraud et al., 2018). Therefore, safety supervision during these periods can also increase the risk reduction of these tasks.

4.2 Analysis of accident investigation reports

After identifying the literature-based contributing factors in the previous step, accident investigation reports were collected to be reviewed. This step aimed to examine the contributing factors and causes of the accidents in the food and beverage industry in the province of Quebec. The accident investigations reports are published by workers' compensation boards in each province of Canada. CNESST has provided a reliable database for accident investigation reports across the province of Quebec. CNESST investigation reports of accidents in the food and beverage industry were collected and reviewed. From 2000 to 2021, 24 serious or fatal accident investigation reports in Quebec's food and beverage industry have been presented by CNESST. To collect these reports, the search criteria were based on the food and beverage industry, fatal and serious accidents. Therefore, accidents with no injuries were excluded. To the date of review of accident reports, no fatal or serious accident was reported in 2022 by CNESST in Quebec. The regulations of occupational health and safety in Quebec have been updated after 2018. Therefore, accidents that were investigated before 2018, were based on the previous regulations. In total, it included 16 fatal and 8 serious accidents. Figure 4-1 provides different types of activities performed by workers when these accidents occurred. 8 of these accidents occurred during cleaning operations, and 3 of them led to the death of the workers. Cleaning and sanitation refer to the tasks performed to meet the hygiene and HACCP criteria in the food and beverage industry. For instance, cleaning activities include removing the residue from the previous production batch, by using tools such as heavy hoses and high velocity pumps to clean the equipment and the work environment. In the table, material loading, unloading, and storage refer to handling goods from trucks or inside of the factory while storing them. Unjamming and troubleshooting activities represent the unplanned intervention with machines. For example, removing a defective bottle from the production line that caused a stoppage, is categorized in this group of activities. Maintenance, modification, and installation refer to the planned stoppages. For instance, regular maintenance of the machines or installing a new pump in the system are classified under this group of activities.

All the accident investigation reports provided by CNESST followed the same method. They all included causes of the accidents, chronological steps of the events leading to the accidents, laws, and regulations, verification of the proposed causes, and recommendations to prevent similar accidents in the future. Accidents during cleaning operations were collected for further review in this research. It should be noted that in several accidents, there were multiple contributing factors.

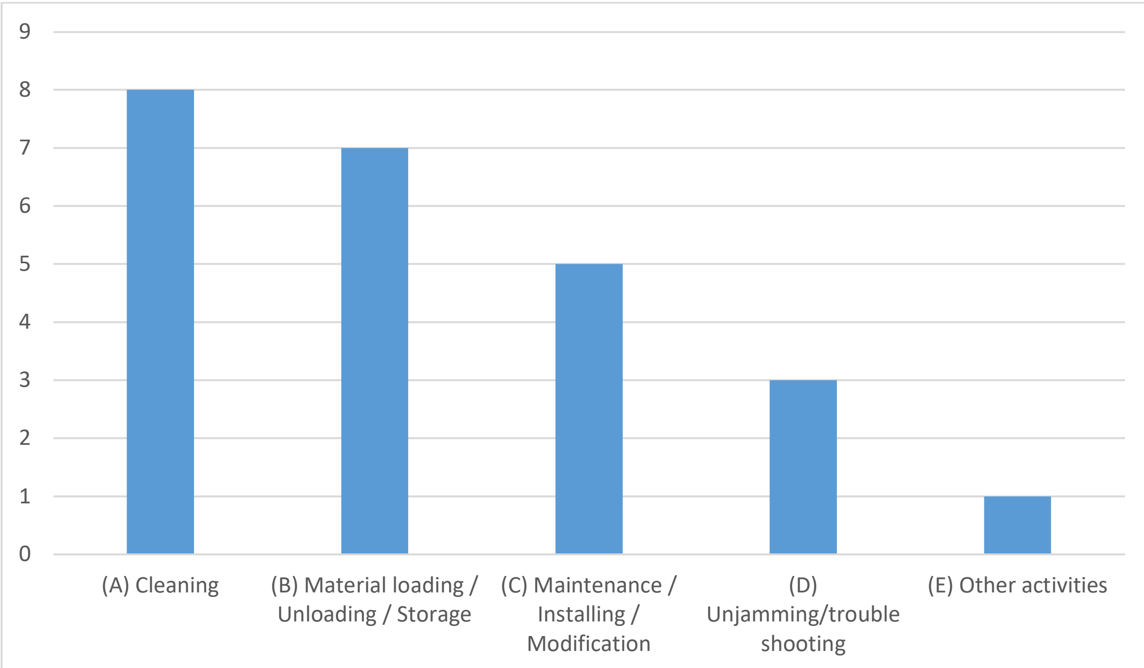

Figure 4-1 Occurrence of the accidents based on the types of activities (www.cnesst.gouv.qc.ca).

Table 4-2 provides an overview of all the 24 accidents in the food and beverage industry. This table presents accident types, equipment, or machine involved in the accident and contributing factors. Lack of supervision and unsafe working methods were the two contributing factors, reported in most accidents. In some cases, although similar near misses had occurred before the accidents, no corrective action had taken place. The training was improper, oral, or not up to date for the workers. Moreover, a lack of preventive maintenance plans for all equipment parts was a common cause in these accidents. Poor design of the machines, accessible jamming and hazardous zones, and layout of the on, off, and emergency stop buttons were repeatedly identified as the technical contributing factors.

Table 4-2 Overview of the 24 accidents in the food and beverage industry during 2000-2021 in Quebec (www.cnesst.gouv.qc.ca).

Accident type/ CNESST report number	**Equipment**	**Causes/ Contributing factors**		
		Individual	**Organizational**	**Technical**
Caught in moving parts/ 4270, 4277, 4004, 4000, 3961, 3456, 3602, 3219, 3214.	Meat grinder (mincer)/ lift table/ stunning box (slaughter) machine/ apple bin tipper/ depalletizer/ mussel sorting machine/ bottle labeller machine/ conveyor/ dock leveler.	Unintentional start of the operation/ inexperienced worker.	Lack of supervision/ unsafe working method/ cleaning task in the evening shift/ prevention program not available/ lack of corrective actions/ no proper training for lockout for cleaning/ no written lockout procedure for cleaning/ PM was not updated/ inappropriate PPE/ deficient health and safety management/ understaffed, seasonal workers/ verbal trainings.	Absence of machine manual/ design and layout of the start, stop and emergency stop button/ machine design needs frequent cleaning/ accessible jamming zones/ infrared sensor controls the movement/ cleaning performed in operation mode/ modification in the machine (automated).
Electrocution / 4329, 4266, 3315, 3203.	Circuit breaker/ pump's motor/ welding machine.	Not electrically certified personnel.	Night and weekend shift/ deficient health and safety management/ lack of supervision.	Poor risk assessment/ incomprehensive PM program/ unidentified motors.
Fall from height/ 4293, 4303, 4195.	Truck/ forklift/ trailer/ open doors in the second floor.		Unsafe working methods/ deficient health and safety management.	Unsafe storage method/ unorganized work environment/ faulty carriage/ absence of PM and inspections for shelves.

Table 4-2 Overview of the 24 accidents in the food and beverage industry during 2000-2021 in Quebec (cont'd and end).

Hit by falling objects/ 4253, 3722, 3303.	Storing shelves/ trolleys/ heavy bags.	Rush in moving between the shelves.	Unsafe storage method/ different types of manufacturers.	Poor assembly of the shelf.
Hit by heavy machinery/ 3934, 3545, 3395.	Truck/ trailer/ loader.	Parking brakes not engaged/ parked in slope without a stopper/ lack of communicati on	Unsafe working method/ simultaneous operations/ deficient site entry policy/ deficient health and safety management.	-
Splash of hazardous chemicals/ 3939.	Bottle water compartment (full of hot caustic).	-	Deficient Health and safety management/ no corrective action/ unsafe working methods/ lack of training.	Deficient alarm management system.
Fire/ 3896.	Recirculatory line.	-	Hazardous procedure for the hot work.	Poor maintenance of the shutoff valve/ ineffective protection of the oil level indicator/ poor risk assessment.

Based on the accident reports reviewed in the food and beverage industry, risk reduction measures are identified and categorized into three groups of individual, organizational and technical. Individual risk reduction measures need to be implemented by the individuals working in the industry. For instance, when system verification needs to be done only by certified and authorized personnel, the workers need to respect the procedures. Organizational factors cover areas of the organization, such as health and safety or production department, or the whole organization, from top managers to shopfloor workers, are involved. For instance, in cases relevant to safety culture, or when safety meetings have been postponed for a long time, or supervision and safety inspections of machines and workplaces have not been done on a timely basis, organizational risk reduction measures are needed. Also, deficient safe work practices and methods are classified as organizational factors. Different departments of an organization should be accountable for providing up to date, comprehensive, and practical safe work practices for each task. Technical factors are most relevant to the design of machines or workplaces. For example, defective interlocks or improper position of a start button or emergency push button are in this category. Risk reduction measures are recommended by the investigators of the accidents based on standards and observations of the workplace. Table 4-3 provides details in this regard.

After careful reviewing of all the accident reports, it was concluded that cleaning was the most reported activity that was taking place during the occurrence of the accidents. Therefore, the focus of this study will be on the 8 accidents that happened during cleaning operations. The year of the accident, accident type, shift of the work, number of the victims, the machinery involved, and direct causes are shown in table 4-4. Based on the findings, 6 of 8 accidents happened during evening and night shifts and only 2 of them occurred during the day. Also, 2 of the accidents occurred due to electrical hazards and 6 due to moving parts of machines. In total, 3 workers died, and 7 workers were seriously injured.

Table 4-3 Risk reduction measures retrieved from the accident reports (www.cnesst.gouv.qc.ca).

Activity	Hazards	Risk reduction measures		
		Individual	**Organizational**	**Technical**
Cleaning	Electrical energy/ machinery moving parts.	Only qualified and certified personnel can repair and fix the electrical system.	Safe work procedures/ personnel safety training/ training on lockout/ develop a lockout procedure/ written safety training and lockout procedure/ lockout procedure for cleaning/ safety training for workers.	Certified electrician/ safety devices in compliance with standards/ functional interlock systems/ reconnect the safety module/ daily checks of the safety systems/ PM for all parts of electrical equipment/ pre-use inspection of electrical equipment/ lifting tables were modified to be safe/ relocation of the control devices/ install the safety guards/ modification the machine/ lockout application/ installing light and sound indicators for operation mode of the conveyors/ accessible emergency stop button/ installing safety guards for hazardous zones.

Table 4-3 Risk reduction measures retrieved from the accident reports (cont'd).

Loading / unloading / storage	Work at height, falling objects, Moving heavy machinery and trucks	Authorized personnel can use forklifts. Certified personnel only can assemble shelves.	Annual inspection of company's forklifts, safety training, ban of bulk bag storage out of metal structures, ban of more than 2 layers of storage, Training for workers, visitor policy in place, safe working methods, safety training for drivers for trailers hitching/unhitching, auditing and inspections of all parking spots	Pre-use inspection of forklifts/ job hazard analysis/ use of elevating platform/ installation of bumpers on all slopes/ shelves assembly by certified personnel.
Maintenance/ installing/ modification	Work at height/ hazardous chemicals/ fire/ electrical energy.	Certified personnel only can verify electrical systems.	Safe working methods/ training and supervision/ PM of refrigeration system/ PM in place for all electrical cords and connections/ training for workers about electrical risks and safety.	Alarm management system/ purging, ventilating, and cleaning of lines before the hot work/ oil level indicator compatible with the standards/ verification of all welder's machines and factory electrical system/ visual pre-use inspection of the cords.

Table 4-3 Risk reduction measures retrieved from the accident reports (cont'd and end).

Unjamming/ troubleshooting	Moving parts of machinery	Certified personnel can modify machines.	Lockout procedure/ establish an action plan/ safety training/ PM should be in place/ prohibition of work on docks from rear side/ revision of safety procedures/ providing warning and prohibition signages on loading docks.	Modifying the machine to be safe/ lockout application/ installing guards and protective safety devices on all machines.
Other	Moving heavy machinery and trucks	-	Prohibition of simultaneous worker moves and heavy machines/ management of access to the working site/ site layout and signage.	Entrance detection system (magic eye).

Table 4-4 Overview of the cleaning related accidents that occurred during 2000-2021 in Quebec (www.cnesst.gouv.qc.ca).

Accident type	**Shift**	**Machinery / Equipment**	**Number of fatalities**	**Number of serious injuries**	**Direct cause(s)**	**CNESST report number**
Electrocution	Night	Circuit breaker	0	3	Deficient electrical risk identification	4329
Caught in machinery	Day	Meat grinder	0	1	Bypassed interlocks/ absence of lockout	4270

Table 4-4 Overview of the cleaning related accidents that occurred during 2000-2021 in Quebec (cont'd and end).

Electrocution	Night	Pump's electro motor	0	1	Deficient grounding	4266
Caught in machinery	Evening	Lift table	1	0	Unintentional activation of the machine/ absence of lockout	4277
Caught in machinery	Night	Slaughter machine	1	0	Unintentional activation of the machine/ absence of lockout	4004
Caught in machinery	Evening	Apple bin tipper	1	0	Removed guards under the tipper	4000
Caught in machinery	Day	Mussel sorting machine	0	1	Absence of lockout/ accessible danger zones	3456
Caught in machinery	Night	Conveyor	0	1	Unintentional activation	3214

In the following table, causes and contributing factors are reviewed based on the number of repetitions in the accidents that occurred while cleaning. This is an indicator of the importance of the contributing factors. It should be noted that "Deficient health and safety management" includes lack of risk identification and assessment, absence of follow-ups with corrective actions, lack of workplace supervision, and absence of safe working procedures. Table 4-5 provides detailed information in this regard.

Table 4-5 Summary of the causes and contributing factors leading to cleaning related occupational accidents (www.cnesst.gouv.qc.ca).

Causes / Contributing factors	**Number of repeats**	**CNESST Report No.**
Deficient health and safety management	8	4277, 4270, 4004, 3456, 3214, 4000, 4329, 4266
Absence of lockout	6	4270, 4277, 4004, 4000, 3456, 3214
Lack of proper training	5	4270, 4004, 4000, 3456, 3214
Poor machinery design	3	4277, 4004, 4000
Removed safety guards/ accessible jamming zones	3	4270, 4000, 3456
Incomprehensive PM program/ lack of preventive maintenance	2	4270, 4266,
Absence of machine manual	2	4270, 3456
Unidentified equipment	2	4266, 4270,
Inexperienced/ seasonal workers	1	4000

4.2.1 Discussion of accident reports and analysis

Deficient health and safety management was the most common cause in accidents. By establishing accountable and reliable health and safety management in the workplace, such accidents can be prevented, or their consequences can be mitigated. For instance, having a plan for regular workplace inspections, improving the safety culture, providing safe operating procedures for different tasks, and pursuing corrective actions could have prevented the accidents. After any modifications in the design or operation of the machines, a new risk assessment needs to be conducted to verify if all the new risks are managed. Also, a risk assessment should take place before purchasing new machines. A proper health and safety program includes regular and refreshing training for experienced and inexperienced workers. As expected, the absence of lockout and removed guards were two of the main causes of most of the accidents. In some cases, preventive maintenance was in place, however, it did not cover all parts and equipment. Moreover, the lack of safe operating procedures for different tasks such as unloading, maintenance, and cleaning was not available or out of date. Improper machine design was another important cause of the accidents. A poor or unsafe design can lead to the accumulation of debris and residue parts, resulting in more demand for cleaning. Furthermore, the poor design and layout of the start and stop buttons, emergency stop push buttons, and design of the control panels can lead to accidents. For instance, in one accident, the start button was designed close to the jamming zone and caused the unintentional start of the machine. In addition to the poor design, intervention with an energized machine was the other cause of this accident.

A review of all the accident investigation reports across Quebec and the literature review indicates several issues that are common between all of them:

- Cleaning and maintenance are operations with the most need for workers to intervene with machines and equipment.
- Level of intervention of workers with machines in the food and beverage industry is relatively high, as hygiene and quality standards require more cleaning, and machines are complex.
- Despite CSA Z432-04 specifying the necessity of maintenance and upkeep of safety devices of every machine, in multiple circumstances, there was no specific maintenance log in place.
- In number of cases, training for new employees or temporary workers took place only by companionship and without written directions or training records.
- Seasonal workers exposed to higher risks, as the food and beverage industry might hire new workers without relevant experience to perform a task for a short time.
- In some organizations, supervisors focused more on quality issues and HACCP than occupational health and safety.
- Some organizations believe that productivity is against safety methods such as lockout, and consider them a waste of time.

- Risk assessments on personal protective equipment (PPE) were done from the quality point of view. Health and safety assessments of the PPE were not conducted based on the working conditions.
- Workers observed defects or faults in safety devices. However, they were neglected, either by themselves or their supervisors.
- Sanitization and cleaning tasks usually occur during the night and the weekend shifts, when supervision is low, and cleaning related accidents usually occur during these shifts.

4.3 Checklist

One of the objectives of this research was to introduce a tool for the assessment of occupational safety in the food and beverage industry. This assessment tool covered the possible accident causes and contributing factors during non-routine operations such as cleaning, planned, and unplanned interventions with machines, equipment, and processes. Furthermore, the risk reduction measures are included in the checklist, so it makes it possible for the user to identify the gaps and areas for improvements in the food and beverage production facility. The checklist is provided based on causes, contributing factors, risk reduction measures, recommendations, and solutions retrieved from accident investigation reports from CNESST, scientific papers, reports from research institutes such as IRSST and INRS, codes, and relevant standards such as ISO 12100:2010, OSHA 1910, and CSA Z460:20. The checklist is formed of seven groups of statements. These groups were chosen based on the repetition and importance of the review conducted on accident reports and scientific papers. For instance, having a preventive maintenance plan and deficient health and safety management were repeated in most of the reviewed literature. The sentences or observations are designed to help the user identify the potential causes and contributing factors in their workplace. There are two ways to respond to each statement, by choosing "Yes" or "No". The first sets of statements (No. 1) are designed to help the user in the identification of hazards in the workplace and potentially hazardous tasks. Therefore, each time the "Yes" is chosen for these sentences, the hazard is in place and the assessor/user should consider the hazards. The No. 2 to No. 7 sets of statements are based on good practices. Therefore, when "Yes" is chosen, it means that risk reduction measure is in place and contributing factors are controlled. However, every time that "No" is chosen, it is an indicator of the possible causes or contributing factors to accidents in the organization and workplace. Therefore, the user will know the vulnerabilities in the company and can take further corrective actions. Table 4-6 presents the checklist in detail.

Table 4-6 The checklist; an assessment tool for potential hazards, causes and contributing factors identification.

No. 1	**Hazard identification in the workplace**	**Yes**	**No**	**Remarks**
1.1	The task is performed at height.	☐	☐	
1.2	The task is performed in the hazardous area of machines (moving parts).	☐	☐	
1.3	It is required to enter confined spaces.	☐	☐	
1.4	It is needed to use hazardous chemicals.	☐	☐	
1.5	The task is performed in extremely hot or cold environments.	☐	☐	
1.6	The task is performed in a noisy environment.	☐	☐	
1.7	The task is performed in an environment with vibrations.	☐	☐	
1.8	There is a possibility of slips, trips, and falls.	☐	☐	
1.9	Heavy materials or tools need to be used, moved, or carried.	☐	☐	
1.10	There is a potential for ergonomic hazards to the worker.	☐	☐	
No. 2	**Safe operating / work procedures (SOPs)**	**Yes**	**No**	**Remarks**
2.1	SOPs are available for each specific non-routine activity.	☐	☐	
2.2	Job hazard analysis (JHA) is carried out before performing non-routine activities.	☐	☐	

Table 4-6 The checklist; an assessment tool for potential hazards, causes and contributing factors identification (cont'd).

2.3	Application of lockout is mentioned in the SOPs for cleaning tasks.	☐	☐	
2.4	In cases that application of lockout is not possible, a risk assessment or other alternatives (with level of risk reduction equal to lockout) are conducted and applied.			
2.5	Only electrical certified personnel are authorized to fix, repair, and verify electrical equipment.	☐	☐	
2.6	There is an up to date, written, and documented lockout procedure in place.	☐	☐	
2.7	Safety systems are checked on daily basis.	☐	☐	
2.8	Electrical equipment is inspected prior to each use.	☐	☐	
2.9	Electrical cords will be visually inspected prior to use.	☐	☐	
2.10	Only authorized personnel can use forklifts.	☐	☐	
2.11	Storing shelves can only be assembled by certified personnel.	☐	☐	
2.12	Forklifts are visually inspected prior to each use.	☐	☐	
2.13	Storage of bulk bags out of metal structures is forbidden.	☐	☐	
2.14	Storage of bulk bags more than two layers is forbidden.	☐	☐	
2.15	Job Hazard Analysis (JHA) is conducted for activities.	☐	☐	

Table 4-6 The checklist; an assessment tool for potential hazards, causes and contributing factors identification (cont'd).

2.16	Elevating platforms are used to have access to out of reach places.	☐	☐	
2.17	There is SOP for drainage of equipment.	☐	☐	
2.18	The alarm management system is in place (alarms cannot be neglected without proper action).	☐	☐	
2.19	All welding machines will be verified to be compatible with factory's electrical system.	☐	☐	
2.20	An action plan with safety considerations specifically for trouble shooting / unjamming is in place.	☐	☐	
2.21	CIP machines are used for cleaning inside the pipes and vessels.	☐	☐	
2.22	In case of cleaning the area close to hazardous moving parts, tools (e.g., long brushes, hoses) are used to perform the task from a safe distance.	☐	☐	
2.23	For cleaning the moving parts, reduced speed mode is set and used to prevent from machinery related accident.	☐	☐	
No. 3	**Preventive maintenance (PM) program**	**Yes**	**No**	**Remarks**
3.1	All parts of electrical equipment are included in the PM.	☐	☐	
3.2	Electrical cords and connections of equipment are included in the PM.	☐	☐	

Table 4-6 The checklist; an assessment tool for potential hazards, causes and contributing factors identification (cont'd).

3.3	Safety devices (such as interlocks and guards) are functional in compliance with standards.	☐	☐	
3.4	Safety devices (such as interlocks and guards) are installed and maintained in compliance with standards.	☐	☐	
3.5	Forklifts are inspected on an annual basis.	☐	☐	
3.6	all parts of refrigeration system are included in the PM.	☐	☐	
3.7	PM covers storage shelves and structures.	☐	☐	
No. 4	**Training of workers**	**Yes**	**No**	**Remarks**
4.1	There is a comprehensive training for lockout for workers who do activities in close contact of machines (such as cleaning).	☐	☐	
4.2	Refresher trainings are instructed on a regular basis.	☐	☐	
4.3	Seasonal and inexperienced workers will receive the complete, formal, and written safety training, before start of any task.	☐	☐	
4.4	Personnel pass safety training about forklifts.	☐	☐	
4.5	There is a policy for safety training and SOP of visitors.	☐	☐	
4.6	Drivers pass the safety training that includes safe hitching / unhitching of trailers.	☐	☐	
4.7	Parking spots are inspected and audited regularly.	☐	☐	

Table 4-6 The checklist; an assessment tool for potential hazards, causes and contributing factors identification (cont'd).

4.8	Personnel receive special electrical safety training.	☐	☐	
No. 5	**Health and safety management**	**Yes**	**No**	**Remarks**
5.1	There is a specific Health and Safety department / committee in the company.	☐	☐	
5.2	Health and safety meetings are held on a regular basis.	☐	☐	
5.3	Health and safety meetings are not postponed for more than a month.	☐	☐	
5.4	Site visits are performed by members of the health and safety department.	☐	☐	
5.5	There is a system to receive and track near-miss reports from workers.	☐	☐	
5.6	In case of receiving a near miss report, corrective actions are recommended.	☐	☐	
5.7	Incident investigations are done as soon as possible.	☐	☐	
5.8	There is a system in place to track implementation of corrective actions.	☐	☐	
5.9	Permit to work (PTW) is in place.	☐	☐	
5.10	Lines are purged, ventilated, and cleaned before the hot work.	☐	☐	
5.11	Warning and prohibition signages are in place.	☐	☐	

Table 4-6 The checklist; an assessment tool for potential hazards, causes and contributing factors identification (cont'd).

5.12	Risk assessments and hazard identifications are performed by safety experts and are updated.	☐	☐	
5.13	For the selection of PPEs, the health and safety committee consider the risks of the workplace and assigned tasks.	☐	☐	
5.14	After each change in the machines, equipment or processes, health and safety experts conduct new risk assessments and take proper actions.	☐	☐	
5.15	Workplace and householding are well organized.	☐	☐	
5.16	Warning and prohibition signages are visible and free of dirt.	☐	☐	
No. 6	**Machine or equipment design**	**Yes**	**No**	**Remarks**
6.1	Control devices are positioned in safe places (not to be damaged during operations).	☐	☐	
6.2	Emergency stop buttons are accessible from the jamming/ hazardous area.	☐	☐	
6.3	In case of modifications in machines, they are verified, and machine's risk assessments are performed by certified personnel.	☐	☐	
6.4	Start buttons are not located close to the jamming zones.	☐	☐	
6.5	On the panels, start and stop buttons (commands) are not located next to each other.	☐	☐	

Table 4-6 The checklist; an assessment tool for potential hazards, causes and contributing factors identification (cont'd).

6.6	Hazardous zones are equipped with safety guards.	☐	☐	
6.7	Removed guards will be installed before the start of the job.	☐	☐	
6.8	Conveyors are equipped with light and sound indicator for the operating mode.	☐	☐	
6.9	Manuals of machines and equipment are available and documented.	☐	☐	
6.10	Equipment and machines used in the facility are modern and new.	☐	☐	
6.11	A unique identification number is assigned to all machines and equipment for inspections and maintenance purposes.	☐	☐	
6.12	Machines are designed to reduce the need for cleaning (for example, self-cleaning machines).	☐	☐	
6.13	CIP machines are used for cleaning inside the pipes and vessels.	☐	☐	
6.14	Safety guards are designed with safe openings (e.g., small gaps or positioned far from hazards) for cleaning purposes.	☐	☐	
6.15	Machines are equipped with dead man's switch to assure the safe activation of the moving parts.	☐	☐	
6.16	Machines are designed with a reduced speed mode (for cleaning the moving parts).	☐	☐	

Table 4-6 The checklist; an assessment tool for potential hazards, causes and contributing factors identification (cont'd and end).

No. 7	**Other**	**Yes**	**No**	**Remarks**
7.1	Experienced workers will perform the task.	☐	☐	
7.2	Tasks will be done during the day shift.	☐	☐	
7.3	Tasks will be done during the weekdays.	☐	☐	
7.4	Speed bumpers are installed on parking spots on slopes.	☐	☐	
7.5	Simultaneous transport of heavy machinery and pedestrians on the same pathway in the worksite is prohibited.	☐	☐	
7.6	Access to working sites is managed and monitored (for example, by magic eye).	☐	☐	
7.7	The site layout is provided at the entrance.	☐	☐	
7.8	Ergonomic assessment for tasks has been conducted.	☐	☐	
7.9	Safety regulations and signage are provided at the entrance.	☐	☐	
7.10	Safety regulations and signage are provided within the site.	☐	☐	

4.3.1 A scenario-based case study

To illustrate the application and assess the effectiveness of this checklist, an accident report from CNESST was studied using the checklist as an example. The accident occurred in November 2016 in Quebec. A worker was seriously injured while removing debris of meat from a meat grinder. He was working close to the screws of the grinder when the accident took place. Potential causes and contributing factors were identified during the use of the checklist which was an indicator of its effectiveness. The results from the assessment of this accident report are presented in the following table. Only those observations that indicated potential causes or contributing factors to the accidents are shown in the table 4-7. As mentioned earlier, in the first series of statements (No.1), choosing “Yes” and in the statements from 2 to 7, every “No” can be an indicator of a potential hazardous situation or task.

Table 4-7 Use of checklist to assess the safety of workplace based on accident report (EN-004270, www.cnesst.gouv.qc.ca). While 1.2 to 1.10 are related to hazard identification, 2.1 to 6.11 are the risk reduction measures.

No.	Observation:	Yes	No	Remarks
1.2	The task is performed in the hazardous area of machines (moving parts).	☒	☐	Cleaning inside the mixer
1.8	There is a possibility of slips, trips, and falls.	☒	☐	Poor layout design
1.10	There is a potential for ergonomic hazards to the worker.	☒	☐	He needs to hunch over
2.1	SOPs are available for each specific non-routine activity.	☐	☒	Not for cleaning
2.3	Application of lockout is mentioned in the SOPs for cleaning tasks.	☐	☒	-
2.4	In cases that application of lockout is not possible, a risk assessment or other alternatives (with level of risk reduction equal to lockout) are conducted and applied.	☐	☒	Absence of a risk assessment or an alternative

Table 4-7 Use of checklist to assess the safety of workplace based on accident report (EN-004270, www.cnesst.gouv.qc.ca). While 1.2 to 1.10 are related to hazard identification, 2.1 to 6.11 are the risk reduction measures (cont'd).

2.6	There is an up to date, written, and documented lockout procedure in place.	☐	☒	-
2.7	Safety systems are checked daily.	☐	☒	Not functional
2.15	Job Hazard Analysis (JHA) is conducted for activities.	☐	☒	-
2.22	In case of cleaning the area close to hazardous moving parts, tools (e.g., long brushes, hoses) are used to perform the task from a safe distance.	☐	☒	A short brush was used
2.23	For cleaning the moving parts, reduced speed mode is set and used to prevent from machinery related accident.	☐	☒	Not available
3.3	Safety devices (such as interlocks and guards) are functional in compliance with standards.	☐	☒	Not functional
3.4	Safety devices (such as interlocks and guards) are installed and maintained in compliance with standards.	☐	☒	Broken / removed
4.1	There is comprehensive training for lockout for workers who do activities in close contact with machines (such as cleaning).	☐	☒	-
5.4	Site visits are performed by members of the health and safety department.	☐	☒	-
5.8	There is a system in place to track the implementation of corrective actions.	☐	☒	-

Table 4-7 Use of checklist to assess the safety of workplace based on accident report (EN-004270, www.cnesst.gouv.qc.ca). While 1.2 to 1.10 are related to hazard identification, 2.1 to 6.11 are the risk reduction measures (cont'd and end).

5.12	Risk assessments and hazard identifications are performed by safety experts and are updated.	☐	☒	-
6.1	Control devices are positioned in safe places (not to be damaged during operations).	☐	☒	Not functional
6.6	Hazardous zones are equipped with safety guards.	☐	☒	Not in place
6.7	Removed guards will be installed before the start of the job.	☐	☒	-
6.9	Manuals of machines and equipment are available and documented.	☐	☒	Not available
6.11	A unique identification number is assigned to all machines and equipment for inspections and maintenance purposes.	☐	☒	Machines without numbers
6.14	Safety guards are designed with safe openings (e.g., small gaps or positioned far from hazards) for cleaning purposes.	☐	☒	-
6.15	Machines are equipped with dead man's switch to assure the safe activation of the moving parts.	☐	☒	-
6.16	Machines are designed with a reduced speed mode (for cleaning the moving parts).	☐	☒	-

In the accident report assessed by the checklist and its results are shown in tables 4-7, a worker was seriously injured while cleaning inside a meat grinder and removing the residue of meat around the screws. The guards were removed, interlocks were defective, and no lockout was applied. Based on the findings from the checklist assessments, the health and safety management was deficient in the company. For almost a year, interlocks were defective, and guards had been removed from the meat grinder. This accident could have been prevented if the health and safety inspections, audits, or visits had been in place. The training was only done verbally, there were no safe operating procedures available, and workers did not have access to the machine's manual. Unidentified equipment was in place, so during the inspection of safety devices requested from workers, another equipment was inspected by mistake, and it was checked as functional in the records. A job hazard analysis had not been carried out and as a result, the working procedures did not require workers to apply lockout for cleaning operations.

4.4 Good practices and solutions in the food and beverage industry

A review of the causes of accidents, contributing factors, accident investigation reports, and their risk reduction measures in the food and beverage industry, provided information for performing assessments of the factory and workplace. There are methods that can increase the efficiency of machines and productivity and reduce the frequency of performing maintenance. One of the contributing factors to the accidents in the food and beverage industry was productivity. Therefore, methods that can improve productivity, can enhance safety. Implementation of Total productive maintenance (TPM) was recommended in many of these documents. This method improves productivity by setting regular maintenance and reducing the necessity of undesired stoppages. Workers become involved in simple, but important maintenance tasks of their assigned machines and equipment. Achieving such results will be possible after a series of training and companionship by the experienced members of the maintenance and production teams. This will allow workers to understand the safety devices and systems of the machines better, as safety is also one of the pillars in achieving the TPM target. A study about the implementation of TPM in the food and beverage industry over 5 years concluded that an increase in productivity was achieved due to a reduced downtime of machines and equipment. Moreover, improvements in the health and safety of the workplace were identified, as operators were more involved in the adjustment and maintenance of their machines (Tsarouhas, 2007). These responsibilities make operators familiar and aware of their assigned production machines and processes, reducing machine breakdowns.

Autonomous Maintenance (AM) is one of the most important pillars of TPM. Some organizations based on their resources, decide to implement AM instead of all pillars of TPM. If AM is implemented effectively in a company, studies have shown that can greatly impact productivity and hence safety in the workplace improves. A study on the implementation of autonomous maintenance concluded that execution of AM by using tools such as failure mode and effect analysis (FMEA) and reliability-centered maintenance (RCM) on machines in the food and beverage industry, can reduce breakdowns of machines by between 40 % to 60 %. The AM plan implemented during the study was limited to 4 tasks: cleaning, lubrication, inspection, and tightening. FMEA and RCM were tools that help understand all components of machines and therefore, the parts that tend to fail more or need more maintenance were replaced by more reliable parts. Also, the vulnerable components were maintained regularly to omit the need for unplanned maintenance, and intervention of workers with machines and stoppages. Therefore, FMEA and RCM were shown as effective tools to develop productivity in the food and beverage industry. These tools have influenced equipment and machine breakdowns reduction and analytical investigations of machine parts failures (Iswidibyo et al., 2020). A proper maintenance policy in an organization results in the improvement of reliability and maintainability of equipment. It enhances the effectiveness of equipment and machines by minimizing breakdowns, downtimes, failures, and defects (Rotab Khan & Darrab, 2010).

Safe design of machines has been recommended as the priority of all occupational safety experts and research projects for decades, as safe engineering design has been proved to prevent inevitable accidents. In the design stage, changes towards safety are inherent and cost much less than performing modifications after manufacturing and installing the machine or equipment. In the design phase of machines and equipment, cleaning operations should be considered to reduce the demand for cleaning if possible. Self-cleaning equipment or using materials with less need for cleaning, in the manufacturing and construction phase were recommended (Landucci et al., 2014). Self-cleaning equipment such as vessels, mixers, and silos are equipped with proper sprays and nozzles for cleaning purposes. Also, automated CIP machines instead of manual cleaning and sanitation were recommended. Automated CIP was recommended as a reliable and effective solution for reducing the risks of cleaning inside the equipment such as tanks, vessels, pipes, and mixers (HSE UK, 2005).

4.4.1 Recommendations from other sectors

Several literature-based solutions and methods from other industry sectors were identified that can be adapted to the food and beverage industry. However, they need to be studied for effectiveness in the food and beverage industry in future research projects.

Video surveillance systems (such as closed-circuit TV or CCTV) have been utilized for workplace safety assessments and improvements. Studies indicated this technology's effectiveness in identifying and assessing the workplace risks associated with individuals' unsafe acts and behaviors. Advantages of video surveillance system utilization for safety matters are more than in-person site visits; advantages such as accurate accident data for investigations and analysis, longer observation periods without interruption of work activity, and the fact that the observer does not have to be necessarily in the dangerous zone, make it an effective method. Also, replaying the recorded videos can be beneficial for training purposes, and identification of safe acts, practices, and effectiveness of control systems such as risk management procedures (Cocca et al., 2016). On the other hand, such systems need mutual respect and trust between the organization and employees. The CCTV will only be used for workplace safety enhancement and only record videos from the machinery, workers, and work environment.

Lack of proper and up-to-date training was mentioned as a cause and a contributing factor to many accidents. Safety passports (booklets with a history of passed training) have been organized and in place for required training courses regarding safety (Heng et al., 2016). Safety passports allow supervisors to check the level of safety training, date of the last attended training, and other notes regarding any individual who is supposed to perform a high-risk task that needs to be followed by a series of safety precautions such as lockout.

A "visual management tool" was introduced by the French Association of Maintenance Engineers and Managers (AFIM) for minimizing the risk of non-routine tasks. This tool also can improve energy management and is called Securafim. This tool can be effective after implementing the three consequent steps; the first step is the census of all the energy sources, and the second step begins with the identification of all securing devices on the machines and equipment, such as isolation and mechanical blocking. All these identified devices must be marked by signage provided in the introduced tool. The third and final step is to give a sheet for each part of equipment and machines.

This should be affixed with each machine and a map of the machine can make it simple to locate all the energy sources and safety devices. This tool is proven to help workers save time and minimize confusion in finding energy sources on machines. However, this tool needs to be continuously observed to assure that all the visualizations and machine mappings are installed, free of dirt, and dust, and visible. Also, in case of any modifications to machines and equipment, the affixed tools must be updated immediately, and the previous maps must become obsolete and out of access (Blaise J.C. et al., 2017).

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research study focused on regulations and standards, codes, literature review, and accident investigation reports of occupational accidents that occurred during non-routine operations in the food and beverage industry in Quebec. The literature in the field of study was limited. Therefore, the keywords were chosen in accordance with previous research studies, standards, and regulations involving machinery safety in the food and beverage industry. A review of the scientific research papers and relevant books about contributing factors that caused fatal or serious accidents was conducted. A variety of factors were identified: productivity pressure, lack of safety culture, inadequate training, underreporting, deficient health and safety management, and poor design of the machines and equipment. Moreover, the absence of lockout and removed safety guards were mentioned as causes of the accidents. Furthermore, accident investigation reports covering Quebec's food and beverage industry were reviewed and analyzed to identify the risk reduction measures and contributing factors.

The other objective of this research was to present a tool to facilitate the assessment of safety in the food and beverage industry. Therefore, a checklist was provided based on the findings from these reports and the literature review. The causes, contributing factors, and risk reduction measures identified from the scientific papers, books, and accident investigation reports were used to develop a preliminary version of risk identification checklist. To illustrate the implementation of this checklist, as an example, one accident report was used to conduct a scenario-based case study. The identified factors in the workplace were comprehensive and helpful in understanding the workplace's vulnerabilities and verifying the checklist's effectiveness. The conducted scenario-based case study indicated that the checklist effectively identified the causes and contributing factors to the accidents. The checklist is a practical tool for the identification of hazardous conditions and tasks in the workplace. Moreover, it helps the user to implement practices that can minimize or reduce risks in the food and beverage industry. The checklist presented in this study was more generic compared to other tools designed for specific machines and energy isolation purposes. Still, it contains useful results for practitioners in the food and beverage industry. In future studies, the developed checklist will be refined and enhanced based on qualified experts' input, by using the Delphi technique to consolidate and compare the opinions of experts. The Delphi method is a structured communication technique that is helpful in the prediction of the decisions and converging towards the correct answer by using a panel of experts. After utilizing the Delphi technique, the checklist will be validated through real case studies.

One of the assumptions of this study was to consider cleaning an important and hazardous task due to the nature of the food and beverage industry. This assumption was substantiated by reviewing the fatal and serious accidents in the food and beverage industry, from 2000 to 2021 in Quebec. It was concluded that most of these accidents occurred while cleaning-related tasks. The logical explanation behind this phenomenon was that cleaning operations are a crucial part of the production in the food and beverage industry, with higher frequencies compared to other sectors. Moreover, cleaning usually occurs in close contact with the hazardous energies and environments; hazardous energies such as electrical, pneumatical, mechanical, and hazardous environments such as confined spaces, slippery floors, and hot surfaces. Furthermore, the pressure from the production schedule was assumed to increase the risk of cleaning tasks.

Furthermore, literature-based contributing factors, causes and risk reduction measures of the available studies from different countries were identified and analyzed. Moreover, other risk reduction measures and recommendations were collected from the accident investigation reports. After reviewing the risk factors in these reports, it was concluded that they were the same in the accidents that occurred in Quebec.

Finally, literature-based recommendations and good practices were presented. These solutions can improve health and safety and minimize the risk of fatal and serious accidents in the food and beverage industry.

In conclusion, this research study contributed to the field of occupational safety, with focus on cleaning operations in the food and beverage industry which was unique. A great database of scientific papers, accident statistics, and accident reports resulted as one of the outcomes of this research. Moreover, performing cleaning was evidenced to be hazardous by reviewing the fatal and serious accident investigation reports in the province of Quebec, from the year 2000 to 2021. Furthermore, the identification of causes, contributing factors, and risk reduction measures contributed to the formation of the checklist. The checklist can be used by safety supervisors to identify the hazards in the workplace and implement risk reduction measures. In addition, best practices such as self-cleaning equipment, CIP, TPM, and AM that can improve safety in the food and beverage industry were proved to be effective practically in scientific papers. Therefore, they were recommended for implementation in the industry. Self-cleaning equipment can minimize or reduce the frequency of cleaning tasks performed by workers. For instance, the installation of nozzles inside a vessel can omit the need for confined space entry to perform cleaning. Furthermore, the use of materials that are easier to be cleaned in the manufacturing phase of the equipment can reduce the frequency of the cleaning tasks. Cleaning in place or CIP machines reduce the need to perform cleaning in close contact with mechanical parts of equipment, and the exposure time with sanitization chemicals. TPM and AM in the food and beverage industry were also concluded to be effective as they can increase productivity by better reliability and maintainability of the equipment and machines. Therefore, there is less need for workers to intervene with machines.

5.2 Limitations

- Although a literature review was conducted and a comprehensive safety assessment tool for the food and beverage industry was proposed, this study has limitations as follows:
- The assessment of accident reports only covered the province of Quebec. Thus, to expand the study nationwide, it is necessary to study other provinces in detail.
- The available literature on some of the identified contributing factors was limited. For instance, contributing factors such as "attention to hygiene regulations over safety" or "hiring seasonal workers" were only studied briefly in a few papers. Therefore, there is a need to conduct more studies on these factors.
- After conducting the assessment by utilizing the checklist, there might be difficulties in the implementation of some recommendations. For instance, significant time and effort are needed at all levels of organizations to improve the safety culture.
- The presented checklist can help users to identify hazards, causes and contributing factors to accidents, and assess the overall situation of the workplace. Nevertheless, it cannot

replace performing the risk assessments and hazard management systems such as permit to work.

5.3 Recommendations for future research

The checklist presented in this research paves the way for future studies, especially when there is the possibility of various site visits and the implementation of time-consuming and long-term safety programs. A Delphi method and a panel of experts from the industry can be used in future research studies for further development of the checklist and validation process. The proposed checklist can also be compared to other tools in future studies. Moreover, the potential contributing factors that were not prevalent in the literature, such as using seasonal workers for cleaning tasks in the food and beverage industry and cleaning during the night and weekend shifts, can be good topics for future research. Furthermore, manufacturing companies can study and implement the inherently safe design of machines and equipment with consideration of cleaning operations. Recommendations and solutions such as using surveillance or CCTV systems, safety passports, and the introduced toolbox by AFIM can be studied and implemented within the food and beverage industry to identify their effectiveness. The use of surveillance systems in hazardous zones in other sectors such as mining has been studied. However, utilizing them in the food and beverage industry and in zones where hazardous machines and equipment are in place can be a topic for future study to understand whether it is adaptable to this sector. Also, the implementation of safety passports for training purposes is an interesting topic for further research. The lack of training is one of the most important contributing factors to accidents. Therefore, a study on the use of safety passports as a means for validation of the passed training courses prior to the start of the job with a particular machine or equipment is of great importance. The visual management tool introduced by AFIM can be a topic for further study on the energy isolation process in the food and beverage industry. This tool is introduced for energy management of the machines and equipment; however, it needs to be studied for improvements and enhance its effectiveness prior to being fully implemented in this sector of the industry.

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