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POLYTECHNIQUE MONTRÉAL

affiliée à l'Université de Montréal

Understanding and preventing bypassing of safeguards on machinery through an assessment tool based on probability levels

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

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Cette thèse intitulée:

Understanding and preventing bypassing of safeguards on machinery through an assessment tool based on probability levels

Présentée par **Aida HAGHIGHI**

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

a été dûment acceptée par le jury d'examen constitué de :

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DEDICATION

To anyone,

who is concerned about occupational health and safety.

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RÉSUMÉ

La Loi sur la santé et la sécurité du travail est une loi québécoise visant à éliminer à la source, les dangers pour la santé et la sécurité des travailleurs. En assurant la santé et la sécurité au travail (SST), on protégera ainsi les travailleurs contre les risques et interventions dans une zone dangereuse de machine, par exemple. Cela contribuera à maintenir et promouvoir le plus haut niveau de bien-être physique, mental et social des travailleurs dans tous les corps de métiers et professions. Des millions de travailleurs intervenant sur des machines peuvent être exposés à divers phénomènes dangereux, tels que : ceux d'origine mécanique, électrique, thermique, ergonomique ou environnementale, ainsi que le bruit, les vibrations, radiations, matériaux ou contaminants pendant leurs interventions sur les machines. Ces risques peuvent entraîner des blessures graves ou un décès s'ils ne sont pas gérés. Par conséquent, dans le processus de gestion des risques qui menacent la SST, des mesures doivent être adoptées afin de réduire ces risques. Les protecteurs et les dispositifs de protection constituent les mesures de réduction des risques les plus efficaces après la prévention intrinsèque, selon la hiérarchie des mesures de réduction des risques liés aux machines.

Différentes normes et règlements exigent des entreprises qu'elles utilisent des moyens de protection sur les machines : protecteurs et dispositifs de protection. Malheureusement, certains travailleurs violent ces règlements et enlèvent les gardes ou désactivent les dispositifs de protection pour différentes raisons. Conséquemment, ils peuvent finir par avoir accès à une zone dangereuse lorsqu'une machine fonctionne. Un tel comportement dangereux est appelé contournement. Le contournement des moyens de protection est une problématique de SST courante dans la plupart des entreprises et est considéré comme une problématique internationale. C'est la raison pour laquelle l'Association internationale de la sécurité sociale a lancé un projet international avec la participation de l'Allemagne, l'Italie, la Suisse et l'Autriche en tant que groupe de projet afin d'atténuer le contournement des moyens de protection.

Cette recherche propose de prévenir le contournement des moyens de protection et d'en promouvoir l'utilisation en concevant, en appliquant et en améliorant un outil spécifique s'inspirant de la norme ISO 14119. Cette thèse examine trois questions de recherche : 1) Comment les préventeurs des milieux de travail peuvent-ils identifier les incitatifs au contournement des moyens de protection sur leur machine, 2) Comment ces préventeurs peuvent-

ils trouver des mesures préventives pour vaincre le contournement sur leur machine, et 3) Comment peut-on évaluer ces incitatifs afin d'éviter de contourner des moyens de protection de la machine pendant sa phase d'utilisation ?

Cette thèse présente une liste qui couvre un vaste champ de 72 incitatifs possibles au contournement, en se basant sur la littérature. Ils sont classés selon les cinq principales catégories suivantes : ergonomie, productivité, machine ou moyens de protection, comportement et climat d'entreprise. De plus, cette thèse fournit une panoplie de solutions, basées sur la littérature, comprenant 82 mesures préventives afin d'éviter le contournement des moyens de protection; elles sont classées en facteurs d'influence techniques, organisationnels et individuels. L’outil développé, sur la base des catégories d’incitatifs mentionnés ci-dessus, permet d’évaluer le contournement des moyens de protection et prévenir ce contournement lors de la phase d’exploitation des machines. Par conséquent, cette thèse sert non seulement à concevoir un outil mais aussi à améliorer la compréhension du problème du contournement.

L'outil proposé est capable d'estimer qualitativement la probabilité de contournement selon quatre niveaux : faible, modéré, significatif et élevé. Ces niveaux aident les décideurs des entreprises à établir des priorités dans les mesures préventives visant à éliminer ou à réduire les incitatifs de contournement dans leur milieu de travail. Cet outil est testé d'abord avec cinq rapports d'accidents liés au contournement, puis en l'appliquant à quatre entreprises manufacturières et à des machines réelles comme études de cas dans la province de Québec. Au total, cinq préventeurs en SST dans ces entreprises, en tant qu'utilisateurs de l'outil proposé, ont appliqué l'outil à 18 machines et 37 activités. Un questionnaire a permis de recueillir les commentaires des préventeurs en SST. Ces derniers ont trouvé l'outil utile avec un niveau de satisfaction élevé (82 %). Leurs commentaires ont permis d’améliorer l’outil. Ensuite, un processus hiérarchique de l'amélioration de la sécurité est présenté pour les machines et les moyens de protection. Enfin, les résultats de l'outil sont utilisés pour définir des mesures préventives afin d'éliminer ou de réduire les incitatifs, ainsi que pour illustrer comment les préventeurs en SST pourraient utiliser les résultats de l'outil pour définir des mesures préventives dans leur entreprises.

Cette meilleure compréhension de l’enjeu du contournement a permis de concevoir l’outil dédié à la phase d’exploitation des machines pour évaluer les incitatifs sur les machines existantes. Les préventeurs en SST peuvent utiliser périodiquement cet outil dans le milieu de travail pour effectuer des audits et des évaluations, afin de comprendre la raison pour laquelle des accidents liés au contournement surviennent, ainsi que pour prévenir le contournement. Les incitatifs identifiés par les utilisateurs finaux peuvent alimenter les concepteurs de machines en connaissances additionnelles, conformément à la boucle de rétroaction du processus de réduction des risques recommandé par la norme ISO 12100:2010 (boucle représentant le retour d'expérience de l'utilisateur au concepteur de la machine).

Cet outil fournit une approche préventive pour les entreprises: 1) éviter le contournement des moyens de protection en analysant les motifs au contournement plutôt que de blâmer les opérateurs, 2) réduire le nombre d'accidents dus au contournement et, par conséquent, 3) augmenter la productivité.

ABSTRACT

The Act Respecting Occupational Health and Safety is a law in Quebec aiming at eliminating, at their source, dangers to the health, safety and physical well-being of workers. Therefore, ensuring occupational health and safety (OHS) will contribute to protecting workers from risks and entering a hazard zone of machinery; subsequently, it will maintain and promote the highest degree of physical, mental, and social well-being of workers in all professions. Millions of employees working on machines may be exposed to various hazards, including mechanical, electrical, thermal, noise, vibration, radiation, material or contamination, ergonomic, and environmental hazards, during their interventions on machinery. Those hazards can cause serious injuries or fatalities if they are not well-managed. Therefore, in the process of occupational risk management, measures are essential to control the OHS-related risks. Guards and protective devices are the most efficient risk reduction measures, after inherently safe design, in the hierarchy of risk reduction measures associated with machines.

Different standards and regulations require enterprises to use guards and protective devices (safeguards) on machinery. Unfortunately, some workers violate those regulations and remove guards or disable protective devices for different reasons. Therefore, they may end up having access to a hazard zone when a machine is operating. Such unsafe behavior is called bypassing. Bypassing of safeguards has been identified as a common OHS problem in most enterprises, and it is considered to be an international problem. As such, the International Social Security Association began an international project with the participation of Germany, Italy, Switzerland, and Austria as the project group to mitigate bypassing.

This research proposes the prevention of bypassing safeguards and promoting the use of safeguards by designing, applying and improving upon a dedicated tool inspired by the ISO 14119 standard. This dissertation investigates three research questions: i) How can OHS practitioners identify the existing incentives to bypass on their machine? ii) How can OHS practitioners find preventive measures to overcome bypassing on their machine? iii) How can one assess those incentives in order to avoid bypassing safeguards of the machine during the use phase?

This dissertation presents a list that covers a wide scope of 72 possible incentives to bypass based on the literature. They are categorized into five main categories: ergonomics, productivity,

machine or safeguarding, behavior, and corporate climate. In addition, this dissertation provides a collection of literature-based solutions that include 82 preventive measures classified into technical, organizational and individual influential factors to prevent bypassing safeguards. The tool developed based on the above-mentioned groups of incentives helps assess and prevent the bypassing of safeguards at the use phase of machines. Therefore, this thesis serves not only to design a tool but also to improve the understanding of the bypassing problem.

The proposed tool is able to qualitatively estimate the probability of bypassing according to four levels: low, moderate, significant and high. These help decision makers in enterprises prioritize preventive measures to eliminate or reduce incentives to bypass in their workplace. This tool is tested first with five bypassing-related accident reports and then by applying it to four actual manufacturing companies and to real machinery as case studies in the province of Quebec. In total, five OHS practitioners in those companies, as the users of the proposed tool, have applied the tool to 18 machines and 37 activities. A questionnaire enabled feedback to be gathered from the OHS practitioners. Their feedback revealed that the tool was useful with a high level (82%) of satisfaction. The OHS practitioners' feedback also helped improved the tool. Afterwards, a safety improvement prioritization process is presented for the machines and their safeguards. Finally, the results of the tool are applied to define preventive measures to eliminate or alleviate the incentives, as well as to illustrate how the OHS practitioners could utilize the results of the tool to define preventive measures to their companies.

The improved understanding of the bypassing issue enabled the design of the tool dedicated to the machine use phase to assess incentives on existing machines. OHS practitioners can periodically use the tool in the workplace to do audits and assessment in order to understand why bypassing-related accidents happen, as well as to prevent bypassing. Those identified incentives, as end users input, can provide additional guidance to machine designers according to the feedback loop in the risk reduction process recommended by ISO 12100:2010 (loop representing the experience feedback from the machine user to the designer).

This tool provides a preventive approach for the enterprises to: 1) tackle the bypassing of safeguards through an analysis of the incentives to bypass rather than blaming operators, 2) reduce accidents caused by bypassing, and subsequently, 3) increase productivity.

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LIST OF ABBREVIATIONS

CNC	Computer Numerical Control
CNESST	Commission des normes, de l'équité, de la santé et de la sécurité du travail
COIN	Corporate Operational Information System
CSA	Canadian Standard Association
EPICEA	Études de prévention par l'informatisation des comptes rendus d'enquêtes d'accidents du travail
FACE	Fatality Assessment and Control Evaluation
FMS	Flexible Manufacturing Systems
HSE	Health and Safety Executive
HVBG	Hauptverband der gewerblichen Berufsgenossenschaften
IFA	Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident Insurance)
IRSST	Institut de recherche Robert-Sauvé en santé et en sécurité du travail
ISO	International Organization for Standardization
ITB	Incentives to bypass
LSST	Loi sur la santé et la sécurité du travail
NIOSH	National Institute for Occupational Safety and Health
OHS	Occupational Health and Safety
OSHA	Occupational Safety and Health Administration
PPE	Personal Protective Equipment
RIDDOR	Reporting of Injuries, Diseases and Dangerous Occurrences Regulations
RRMs	Risk Reduction Measures
RSST	Règlement sur la santé et la sécurité du travail

TPB	Theory of Planned Behavior
WBS	Work Breakdown Structure

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CHAPTER 1 INTRODUCTION

In 2014, the BLS (2015) reported that 155.9 million laborers could be exposed to hazards during interventions, such as the operations, maintenance and repair on machinery, if occupational health and safety (OHS) measures were absent from the organization or were present in the organization but were bypassed.

The aim of occupational health and safety is (i) to maintain and promote the highest degree of physical, mental, and social well-being of workers in all occupations, (ii) to prevent workers from leaving work due to health disorders, (iii) to protect workers from risks and entering into hazard zones and, (iv) to place and keep workers in an occupational environment that is adapted to their physiological and psychological capabilities (Hesapro, 2013). With regards to machinery, workers are exposed to different potential sources of harm, including mechanical, electrical, thermal, noise, vibration, radiation, material/contaminants, ergonomic and environmental hazards during their interventions. Hence, industries should perform a risk assessment and should consider risk reduction measures to control the risks and to protect the workers from possible injuries and related consequences, such as cuts, burns, shocks, scalding, stress, fatigue, vascular disorders, insomnia, poisoning, musculoskeletal disorders, and slipping (Giraud, 2009; ISO 12100, 2010). OHS rules and procedures require employers and employees to be in compliance to prevent workers from being killed or from suffering work-related injuries.

Risk management is the process of assessing and reducing risk. The risk levels are evaluated after carrying out a risk analysis. The suitable risk reduction measures (RRMs) are applied where the risk level is not acceptable to control risks and to prevent occupational accidents. The hierarchy of risk reduction measures is as follows, in decreasing order of efficiency: (i) inherently safe design, (ii) guards, (iii) protective devices, (iv) information for use (e.g. warning signs), (v) work method or procedures and (vi) personal protective equipment (PPE) (Giraud, 2009; ISO 12100, 2010). This thesis focuses on safeguards, i.e., the second and third types of measures, including guards and protective devices.

> A guard is a *"physical barrier, designed as part of the machine to provide protection which may act either alone or in conjunction with an interlocking device with or without guard locking" (ISO 12100, 2010).*

> Protective devices are “*A safety device may perform one of several functions. It may stop the machine if a hand or any part of the body is inadvertently placed in the danger area; restrain or withdraw the operator's hands from the danger area during operation; require the operator to use both hands on machine controls, thus keeping both hands and body out of danger; or provide a barrier which is synchronized with the operating cycle of the machine in order to prevent entry to the danger area during the hazardous part of the cycle such as light curtain, two-hand control, enabling devices” (OSHA 3067, 1992).*

Despite all of the existing regulations (e.g. the Province of Quebec’s Regulations respecting occupational health and safety, the European Directive on Machinery) and standards (e.g. ISO 12100:2010) that emphasize using these measures, accidents happen due to the absence of safety measures or because of bypassing. In this thesis, “Bypassing is an action that neglects the guards and protective devices or renders them nonoperational such that a machine is operated in a way that is unlike the designer’s intention; the tasks are carried out in a manner that is non-compliant with the requirements or instructions or without required protective measures” (Haghighi, Chinniah, & Jocelyn, 2019). Webster’s International Dictionary defines these as follows: *bypassing means neglecting or ignoring usually intentionally and defeating means undoing or destroying*. The following is an example of a bypassing situation: a worker jams a needle into a start button of a fully automated circular knitting machine and the machine continues to operate while the safety gate is open (NIOSH, 2004). As a result, the worker is crushed by the moving parts and dies.

The bypassing of safeguards is a prevalent problem in industry: for instance, protective devices were defeated in half of the companies in Switzerland (Zimmermann, 2007), and one third of protective devices on metal working machines were bypassed in Germany (Apfeld et al., 2006; IFA, 2011). Furthermore, studies that deal with machine-related accidents identify bypassing as one of the leading causes of accidents in industry. Consequently, this unsafe behavior causes fatalities and serious injuries such as amputations, fractures, crushed parts of body and more. Fourteen out of 106 accidents related to moving parts of machinery, from 1990-2011 in Quebec, were due to removing or bypassing guards and protective devices (Chinniah, 2015a), and protectors were disabled in 8 out of 31 accidents related to industrial robots from 1997 to 2010 (Charpentier & Sghaier, 2012).

To overcome the above-mentioned circumstantial events, the main objective of this research is to design a tool for enterprises, as the machine users, to prevent bypassing in industry and to promote the use of safeguards on machinery. Subsequently, bypassing-related accidents could be reduced and productivity could be increased in enterprises. To reach these objectives, this research identifies the incentives behind bypassing to estimate its probability and presents preventive measures to eliminate or reduce the incentives to bypass.

This PhD research project investigates how the bypassing of safeguards could be prevented and how the use of safeguards can be promoted to provide a safer workplace for workers. Definitions of bypassing, and bypassing-related requirements in various standards, are thoroughly studied. Accident-related studies are reviewed to show that bypassing is one of the contributing causes of accidents in industry, and that the bypassing of safeguards, a common problem, needs to be taken into consideration. Therefore, this research identifies the incentives behind bypassing to prevent this unsafe practice. It also reviews various studies in the field of machine safety to extract the incentives to bypass. Seventy-two possible incentives to bypass are identified and classified into the five main categories that were mentioned above. Then, this research studies risk estimation tools, existing tools for the prevention of bypassing, risk parameters, as well as the number of levels describing the parameters and the risks. Consequently, it develops a holistic assessment tool based on: i) the structure and logic adapted from an existing assessment matrix, which is available in (IFA, 2011), ii) the influencing parameters on estimating the probability of bypassing and the number of levels for each parameter, and iii) a wide scope of the incentives involving ergonomics (e.g., poor visibility), productivity (e.g., time pressure), behavior (e.g., workers' habit), machines or safeguarding (e.g., existing impractical guards), and corporate climate (e.g., lack of management commitment). That holistic aspect of the tool distinguishes it from tools that have been suggested in previous studies (DGUV, 2013; IFA, 2011; Suvapro, 2007). In addition, the new tool is meant for the machine use phase. By applying the proposed tool, occupational health and safety practitioners in enterprises can now identify the existing incentives to bypass and their level of effect in the workplace. Afterwards, the tool estimates the probability of bypassing in four levels: high, significant, moderate and low. Such results can help decision makers in enterprises prioritize the preventive measures to reduce or eliminate incentives to bypass. Finally, this research identifies preventive measures and classifies them according to three influencing factors including technical (e.g, the use of "better quality glass" for better visibility), organizational (e.g., providing appropriate supervision), and individual (e.g., raising awareness). Those factors provide guidance for enterprises to define suitable measures to tackle bypassing, to prevent bypassing-related accidents, and consequently, to increase productivity.

The remainder of the dissertation is organized as follows: Chapter 2 reviews the literature concerning occupational health and safety (OHS), bypassing-related standards, accident-related studies, incentives to bypass, possible solutions to prevent bypassing of safeguards and risk estimation tools. Chapter 3 describes the research objectives, methodology and outputs. Chapter 4 provides useful insights into the incentives for bypassing, as well as preventive measures that could be used as a guideline for researchers and OHS preventionists. In addition, it serves as a foundation for developing a holistic tool to prevent bypassing. Chapter 5 proposes an assessment tool that estimates the probability of bypassing safeguards on machinery. Chapter 6 tests the proposed tool through its application in four companies as case studies and improves upon that tool. Chapter 7 discusses the findings. Chapter 8 presents a conclusion and recommendations.

Two articles published in the Safety Science Journal and another in the Safety Journal (Chapter 4-6) as well as a peer-reviewed conference paper presented at the 13th International Conference CIGI QUALITA (Appendix A) detail the outcomes and contributions of this PhD.

CHAPTER 2 CRITICAL REVIEW OF THE LITERATURE

This chapter reviews different studies to gain more accurate knowledge on the scope of the research project in order to formulate the research questions and to answer them. An overview is carried out on the following areas:

2.1 Bypassing

Some terms are used as synonyms for the concept of bypassing in different fields and various studies, for instance, violation, removing, deactivating, cheating, overriding, disabling, defeating, circumventing, and not using.

The bypassing concept exists in different fields. This unsafe act may occur for different reasons and certain solutions are taken into consideration based on the nature of different fields to prevent injuries and fatalities. Hale and Borys (2013) studied the reasons for violations of safety rules that occurred in the workplace in organizations. Individual factors (e.g., fatigue, "attitude to and habits of non-compliance"), hardware/activity factors (e.g., complicated design), organizational or safety climate factors (e.g., "the management turns a blind eye", poor collaboration between a supervisor and worker), and rule-related factors (e.g., "outdated rules", "difficult to understand") contribute to the violations of safety rules and procedures.

In the field of aerospace safety, Pass (2011) represented health and safety violations as a kind of deviance that will undoubtedly happen in space habitats. Space habitats are identified as confined systems. Destructive accidents can occur in this type of system due to a variety of causes. One of the challenges is to restrain from involvement in health and safety violations for the sake of expediency due to supervisors' pressures. Therefore, this study expressed that such issues should be understood and taken into account at the early stage of the design and construction of space habitats, which are complex systems combining physical and social structures. In addition, that study presented the following recommendations to "ensure the long-term inhabitation of a space habitat": (i) identification and prevention of health and safety violations should be included in the planning process of space habitats, (ii) human should remain the central component in decision-making, (iii) reward mechanisms are necessary for the positive acts carried out by citizens related to the health and safety, (iv) education and training is a priority, and (v) the researcher should begin to study the "health and safety regulations in space habitats."

In the field of vehicle safety: D. Parker, Manstead, Stradling, Reason, and Baxter (1992) applied the theory of planned behavior (TPB) to explore drivers' intentions to perpetrate several driving violations including "drinking and driving, speeding, close following, and overtaking in risky circumstances." The results illustrated that "perceived behavioral control" positively contributes to the prediction of behavioral intentions relating to the foregoing violations. As such, Chen and Chen (2011) integrated the psychological flow variables including perceived enjoyment and concentration into the TPB to predict heavy motorcyclists' speeding behaviors. The results revealed that psychological flow variables can be a great predictor to explain motorcycle riders' speeding behaviors. Moreover, these findings help create road safety measures and develop programs to educate riders. Based on an interview study in Turkey, "situational conditions, not believing in the effectiveness, discomfort and having no habit" were reported as the motives for not using a seat belt (Şimşekoğlu & Lajunen, 2008). To promote the use of seat belts, this study suggested that campaigns and programs should highlight the advantages of the use of a seat belt in terms of safety by training people how seat belts would be effective in accidents, as well as how they could form new habits through behavioral changes and through a change in attitude and motivation. In addition, car occupants' needs should be taken into consideration when designing and producing more convenient seat belts. Horswill and Coster (2002) assessed the impact of "vehicle characteristics," including "internal car noise," "performance," "safety features," and "smoothness and handling," on drivers' risk-taking intentions. The results have shown that the "vehicle performance" and "number of safety features" have an effect on intended risk-taking (higher performance and number of safety measures caused higher risk-taking behavior). The level of internal noise affected close following and "risky gap acceptance". However, it did not influence speed. Smoothness and handling did not influence risk-taking intentions. The authors presented the following measures to promote road safety: (i) considering drivers' behavior feedback in the design of the car, (ii) educating drivers to change their perceptions of vehicle safety, and (iii) persuading drivers to purchase low-powered vehicles that "have been demonstrated to be as crashworthy as" high-performance vehicles. However, they select slower speeds while driving the low-powered cars.

In the field of maritime safety, seafarers may violate safety procedures in the maritime transportation industry due to the combination of (i) the quality of the content of procedures, (ii) the type of work, (iii) the development and management of procedures, and (iii) other sociotechnical aspects. That study stated that the relationship between these conditions should be identified to take sufficient measures in order to enhance the conformity to procedures and to develop risk models integrating "human actions" (Bye & Aalberg, 2020).

In summary, the findings of the above-mentioned studies in different fields have revealed that the occurrence of the bypassing concept is due to human behavior shaped by the context or conditions in which they evolve, as well as technical difficulties. In all, those studies have emphasized suitable design, including human needs, as well as the education of people, in order for behavioral change to minimize the tendency to bypass.

2.2 Bypassing safeguards

Different hazards that exist, including mechanical, electrical, thermal, noise, vibration, radiation, material or contamination, ergonomic and environmental hazards, in a work environment expose workers to severe risks and may cause injuries and fatalities. Therefore, ISO 12100 (2010) presents a process to manage OHS-machinery-related risks. This process includes risk assessment and risk reduction. According to ISO 12100 (2010), risk assessment is a systematic process consisting of a risk analysis and a risk evaluation. Risk analysis provides required information for a risk evaluation. Risk analysis encompasses (i) determining the limits of the machine, (ii) identifying the hazards, and (iii) estimating the risk. A part of step (i) is about identifying reasonably foreseeable misuse such as bypassing. Giraud (2009) introduced a hierarchy of risk reduction measures (RRMs) based on ISO 12100 (2010) in order to control risks at an acceptable level. As previously stated, those RRMs are, from the most to least efficient, (i) inherently safe design, (ii) safeguards, (iii) protective devices, (iv) information for use (warning signs, signals), (v) work methods or procedures and (vi) personal protective equipment (PPE). In some organizations, these RRMs are absent or are present but bypassed. Therefore, workers are exposed to hazardous situations and severe injuries or fatal accidents may occur.

This research only focuses on bypassing safeguards, which includes guards and protective devices. Bypassing is an action that renders protective devices nonoperational. Therefore, the machine is operated contrary to a designer's intent and without required safety measures (Apfeld, 2010; Apfeld et al., 2006; IFA, 2011; ISO 14119, 2013). According to ISO 13855 (2010), defeating the detection zone means accessing the hazard zone "by passing over, under or to the side of the detection zone” without the activation of a protective device. Moreover, the methods of defeating that equipment, such as “crawling below the lowest beam”, “reaching over the top beam”, “reaching through between two of the beams”, and “bodily access by passing between two beams” shall be considered during a risk assessment. As other examples of reasonably foreseeable misuse are defeating ways of the two-hand control device, including (i) using one hand, (ii) using the hand and elbow of the same arm, (iii) using the forearms or elbows, (iv) using one hand and any other part of the body (e.g., knee, hip), and (v) blocking one control actuating device (ISO 13851, 2002).

Because of the importance of the bypassing issue, certain regulations and international standards published by the International Organization for Standardization (ISO) pay attention to it. Protective measures on machinery should be easy to use to achieve the maximum efficiency of the machine. Therefore, the possibility of bypassing and the incentive to bypass protective measures should be considered during the risk estimation. For instance, protective measures might be defeated when they are difficult to use or they disrupt the production process, and so forth (ISO 12100, 2010). Lessening the man-machine interventions during operation and other activities reduces the incentives to defeat (ISO 14119, 2013). In addition, ISO 14119 (2013) contains some required preventive measures to reduce the possibility of defeating interlocking devices in the design phase of the machine. Moreover, it provides an informative guide on the basis of the assessment matrix proposed by IFA (2011) for evaluating the motivations of defeating interlocking devices. Le parlement européen (2009) requires that (i) guards and protective devices must not hinder the visibility of the production, (ii) must be complicated to defeat, and (iii) guards and protective devices must limit reaching into the working zone when carrying out installation, tool exchange or maintenance. Regarding protective devices, ISO 13851 (2002) explains that the protective effect of the two-hand control device should be difficult to defeat. Therefore, this standard provides preventive measures for different ways of defeating the protective effect of the two-hand control device, for example, “separation of the control actuating devices by at least 260 mm (internal dimension)”. ISO 13855 (2010) presents considerations to prevent the circumvention of electro-sensitive protective equipment to avoid accessing the hazard zone. Article 189.1 of (RSST, 2017) emphasizes that a specific control mode should be considered for the machine when the workers inevitably need to reach into the hazard zone to perform tasks while the machine remains wholly or partly in operation with the guards removed or protective devices defeated. CSAZ432 (2016) requires that guards and protective devices not be easily circumvented.

Briefly, some of the requirements of the foregoing standards (ISO 12100, ISO 14119, and others) are related to the machine design phase. On the other hand, other regulations require employers and workers to avoid the bypassing of guards and protective devices. Despite such standards for the safe design of a machine, bypassing still occurs at the machine use phase. Therefore, various studies directly related to bypassing, as well as those related to machine safety, were reviewed to understand the bypassing of safeguards, as well as to find a way to tackle bypassing. Thus, studies dealing with machine-related accidents were reviewed (Section 2.2.1). Then, different references were reviewed to identify the incentives to bypass, to collect preventive measures (Section 2.2.2), and to study the existing preventive tools that were introduced in the references (Section 2.2.3).

2.2.1 Bypassing-related accidents

Various studies described in this section have analyzed machine-related accidents. They revealed that bypassing safeguards is a contributory cause of the accidents they covered.

Vautrin and Dei-Svaldi (1989) analyzed 54 accidents caused by automated systems in France from 1983-1988. They emphasized that manipulation must not be possible and an evaluation of manipulation should be done on protective systems. Järvinen and Karwowski (1993) analyzed eighty-five automated manufacturing-related accidents. They revealed that the safety devices were removed or defeated in 40% of the cases. Charpentier (2005) analyzed 457 automation accident reports from the French EPICEA[1] database in a period of 20 years. The author found that in 45% of those reports, in spite of the presence of guards, accidents occurred due to (i) implementing and utilizing improper guards (35%), (ii) bypassing of guards (30%), (iii) failure of guards (15%). Moreover, Charpentier and Sghaier (2012) studied 31 accidents existing in the EPICEA database during the period 1997-2010. The main cause of failure of protection identified

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[1] EPICEA: Prevention studies through computerisation of investigative reports on work-related accidents (*Etudes de prévention par l'informatisation des comptes rendus d'enquêtes d'accidents du travail*)

was the disabling of protectors. The protector was temporarily defeated in two cases and was permanently bypassed in six cases.

Backström and Döös (2000) identified problems in 76 automated production-related accidents in 21 worksites. Those problems were (i) safeguard failure, (ii) safeguards were not used (removed, circumvented, defeated, decoupled or failed to activate), (iii) safeguards did not stop all machine movements in the hazard zone, (iv) safeguards are not able to provide full protection ("safeguards with too limited a range"). The second problem related to the non-use of safeguards includes causes such as (i) "safeguard removed", (ii) "safeguard seldom used", (iii) "a lot to do or production disturbances", (iv) "inexperience", (v) "do not know". In addition, Backström and Döös (2000) cited that Edwards (1993) found that safeguards were removed or defeated in 16% of accidents related to the computer-controlled equipment. One hundred accident reports during 2002-2007 were reviewed and (i) insufficient design, (ii) lockout failures, (iii) flaw in fault reporting or maintenance, and (iv) bypassing of safety systems were identified as the contributing causes in the occurrence of those accidents (Shaw, 2010).

Dźwiarek (2004) carried out an analysis of 700 accidents in the Polish industry between 1996 and 2002; (i) inadequate response to a sudden event, (ii) utilization of working procedures which did not cover safety requirements, and (iii) attempts to defeat protective systems were the main reasons for accidents. Eight fatal accidents at Flexible Manufacturing Systems (FMS) during the period of 1985-1990 in Finland were analyzed. The causes that led to those accidents were (i) improper or defective, not installed, or switched off safeguards, (ii) easy access to the hazard zone, (iii) crushing by a part of a machine or a workpiece, (iv) confusing controls, (v) inadequate knowledge about how the machine works or what coworkers are carrying out, (vi) not being able to identify hazards, (vii) not being able to eliminate hazards (Mattila, Tallberg, Vannas, & Kivistö-Rahnasto, 1995). Moreover, 37 incidents, including accidents and near misses, at 17 FMS were studied. In one of those cases, the operator reached into the operations area at a loading/unloading station due to human error or because the guard had been removed. Gardner, Cross, Fonteyn, Carlopio, and Shikdar (1999) investigated mechanical equipment injuries in 35 small businesses in Australia. They found (i) the failure to follow known safe work procedures, (ii) non-existent and inadequate guarding, and (iii) poor machine design and poor machine conditions were the most common contributing factors for accidents in those manufacturing businesses. The data was collected from 119 site investigations of work-related fatalities in the agricultural production sector during the period of 1990-1996. “Safety equipment available but not used” was identified as one of the injury risk factors (13.4%) (Pratt & Hard, 1998).

Apfeld et al. (2006) conducted a survey at metalworking companies in Germany by distributing a general questionnaire on the subject of the manipulation of protective devices. Then, Lüken, Pardon, and Windemuth (2006) and Apfeld (2010) overviewed that study. The data gathered from 940 questionnaires returned helped estimate the amount of manipulation. Thirty-seven percent of protective devices were bypassed permanently (14%) or temporarily (23%). OHS experts estimated that 51% of machinery were potential sources of accidents due to defeating, 34% of companies suffered from this problem, and 25% of machine-related accidents were due to defeating. In addition, OHS experts frequently observed the position switches on safety gates that were bypassed during their site visits. Therefore, the machines operated in unsuitable conditions and bypassing led to serious or fatal accidents (KANbrief, 2003). Suva carried out a survey with 300 Swiss enterprises in 2007 (Zimmermann, 2007). The protective devices on production machines and automatic equipment were manipulated in half of those companies, which caused serious injuries or fatalities. Therefore, Suva formed a campaign with objectives that included raising employers’ awareness of the problems of manipulation and the risks that could occur, as well as a reduction in the amount of manipulation. Huelke, Stollewerk, Lüken, and Post (2006) investigated accidents at stationary machines that were in the accident statistics of the HVBG for 1996 to 2000. They identified the possible causes of those accidents: (i) a lack of or insufficient safeguarding of hazard zones, (ii) incorrectly designed or fitted protective devices, (iii) deliberate defeating of safety devices, (iv) unintentional faulty operation due to the insufficient usability of operating and safety equipment, (v) environmental disturbance with transient failures, e.g. electromagnetic interference, (vi) operation of the devices outside the device specifications, (vii) unidentified random device hardware malfunction, and (viii) systematic software errors with transient failures. Moreover, 824 machines in 40 metal fabrication businesses in Minnesota during a period of 16 months were evaluated because metalworking has been identified as an industry with one of the highest rates of non-fatal injuries in the United States. The authors found that machine guarding was not adequate in the metal-working sector (Samant et al., 2006).

In the first phase of recent studies related to the defeating of interlocks on Computer Numerical Control (CNC) machines, the accidents from the COIN[2] and RIDDOR[3] databases were analyzed and 11 out of 23 accidents and 15 out of 20 accidents, respectively, were associated with the manipulation of interlocks (Hopkinson & Lekka, 2013).

In the province of Quebec in Canada, (Chinniah & Bourbonniere, 2006) studied five automation-related accidents retrieved from the CNESST[4] database and the contributory causes of accidents were (i) unintended start-up or machine movement, (ii) inadequate or inappropriate safeguarding, (iii) insufficient training for workers, (iv) underestimating the risks, (v) defeating existing protective devices, (vi) advances in automated systems. Chinniah, Paques, and Champoux (2007) found that the causes of accidents that occurred in the plastic industry in Quebec were (i) entering into a hazard zone through, around, under, or over guards, (ii) removing or bypassing guards and protective devices, (iii) accessing the machine to remove jamming, (iv) not using lockout/tagout procedures, (v) failure of the machine, (vi) being unaware of the machine and its hazards, (vii) using machines with guards insufficiently. According to observations of the 50 factories visited in the manufacturing sector, one of the existing problems related to machine safety in factories in Quebec was the manipulation of safety devices (Chinniah, 2009). The latter suggested (i) training, (ii) implementation of lockout procedures, (iii) improved integration of safety devices, and (iv) better use of machine safeguarding to improve the safety of machinery in Quebec. Chinniah (2015a, 2015b) analyzed 106 accident reports related to the moving parts of machinery. The main causes behind accidents were (i) easy access to the moving parts of machinery, (ii) absence of safeguarding, (iii) lack of lockout procedures, (iv) inexperienced workers, (v) insufficient supervision, (vi) poor machine design, (vii) existing unsafe working methods, (vii)

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[2] COIN (Corporate Operational Information System) database holds accident and incident and HSE (Health and Safety Executive) enforcement and inspection data

[3] The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) requires employers, the self-employed, and a responsible person to record and report serious work related accidents, occupational diseases, and near misses in Northern Ireland.

[4] "*Commission des normes, de l'équité, de la santé et de la sécurité du travail*" in Québec is an organization that sets rules for working conditions, handles pay equity issues, and is Quebec's workplace safety board (reference: http://montrealgazette.com/news/local-news/csst-and-others-to-merge-and-form-cnesst)

absence of risk assessment, (ix) bypassing safeguards. In addition, the author revealed that 14 of those accidents were associated with defeating protective devices or guards.

In summary, despite all of the existing regulations and standards (explained in Section 2.2) that emphasize using those measures, accidents happen as a result of bypassing. A review and analysis of 22 articles dealing with accidents related to machinery (as mentioned above) show that bypassing safeguards is a common issue in different industries and various countries. In addition, it is identified as one of the main contributing causes of accidents. Therefore, finding a reason behind bypassing is an important issue that is drawing the attention of researchers, which will be explained in the following section. That section will help uncover an answer to why employees bypass safeguards, in order to tackle the prevalent problem of bypassing.

2.2.2 Incentives to bypass and preventive measures of bypassing safeguards

Because of the limited references directly related to bypassing, incentives to bypass and their preventive measures, studies associated with machine safety were reviewed to identify the incentives to bypass safeguards on machinery. The HVBG report was the first study related to manipulation, which was carried out in Germany (Apfeld et al., 2006). In the second phase of that study, data related to the benefits of manipulation was collected through a special questionnaire completed for approximately 200 machines. In addition, the research team evaluated the data to develop solutions. The above-mentioned report listed the benefits of bypassing protective devices, including: (i) it is easier or more convenient, (ii) results in faster or greater productivity, (iii) greater use, e.g. for larger workpieces, (iv) greater precision, (v) better visibility, (vi) better audibility, (vii) less physical effort, (viii) reduced travel, (ix) greater freedom of movement, (x) improved flow of movement, (xi) avoidance of interruptions. According to those benefits, the authors have developed several solutions from psychological, ergonomic, organizational and technical perspectives. Some of the suggestions are (i) installing additional operating modes, (ii) improving user-friendliness, (iii) decreasing the ease of tampering, (iv) use of storage of programmable controls, (v) involving operators in procuring the machines, (vi) re-learning the operators, (vii) non-tolerance of tampering by management, (viii) training and increasing awareness, (ix) carrying out visual and functional checks before the initial start-up and production, (x) development of an appropriate safety culture, (xi) improving the machine design, (xii) close cooperation between constructing engineers, electrical engineers, safety equipment suppliers (Apfeld et al., 2006; Lüken et al., 2006). After a while, Lüken et al. (2006) overviewed (Apfeld et al., 2006) and mentioned the benefits of bypassing identified in (Apfeld et al., 2006); in addition, other reasons for manipulation, such as a lack of workspace, are also explained. Meanwhile, those authors suggested solutions for tackling the bypassing of protective devices; for instance, all life cycle of machinery and all modes of operations should be taken into account during the manufacturing phase of a machine. The engineering methods could be applied to decrease ergonomic problems; also, a systematic procedure could be developed by considering technical, organizational and individual levels to stop the circumvention (Lüken et al., 2006). IFA (2011) used some incentives identified by (Apfeld et al., 2006) to design a tool that aims to evaluate the incentives to bypass in the machine design phase. That study stated that the corrective measures must be considered in different phases, including (i) in the design phase (e.g., improving ergonomic design, selecting suitable protective devices), (ii) during the purchase of a machine (e.g., consulting with future operators before machine procurement), and (iii) in the operation of a machine (e.g., modifying the operating process of the machine). Moreover, IFA (2011) added that applying organizational measures is the final solution if the above-mentioned measures are not possible. Hopkinson and Lekka (2013) studied the operators' reasons for defeating interlocks on CNC machines in the second phase of their research based on the interviews with management and group interviews (focus groups) with supervisors and operators in a small number of small and medium sized engineering companies. Those authors classified the factors affecting this behavior according to (i) predisposing factors (e.g. training, experience), (ii) enabling factors (e.g. poor design of machine, impractical safeguards, poor visibility), and (iii) reinforcing factors (e.g. management commitment, disciplinary actions). Moreover, several suggestions were made to prevent defeating such as (i) workers' participation for machine procurement and safety improvements, (ii) raising operators' awareness, (iii) training, (iv) the provision of "evaluation, reward and disciplinary systems", (v) periodic checks by managers and supervisors, (vi) sufficient supervision.

Safeguards were not used or were removed in 35 cases of accidents because (i) there was a lot to do or there were too many production disturbances, (ii) the operator was inexperienced and was not aware of stop devices and their hazards, (iii) the operator did not know why he/she did not use the safety devices, and (iv) the safety device limited observation (Backström & Döös, 2000). KANbrief (2003) identified the possible reasons for defeating position switches on safety gates in the metalworking industry including (i) poor visibility, (ii) repetitive interruption of operations due to malfunctions of switches, (iii) nonexistence of specific operating modes for completing certain operations, (iv) a lack of awareness of the possible risks, (v) switches are accessible and easy to defeat, and (vi) bypassing may be tolerated at the sites. Therefore, a working group was gathered to propose recommendations to avoid bypassing. They considered the most important preventive steps against bypassing: (i) considering ergonomic issues at the design phase of equipment, (ii) making a link between manufacturers and operators, (iii) finding technical solutions and adopting related standards that could make bypassing difficult. However, operators' responsibilities should not be diminished to avoid bypassing.

Achieving successful machine safeguarding systems is problematic for OHS professionals and supervisors. Workers defeat interlocks deliberately based on their own cost-benefit evaluation during their tasks. The ergonomists could increase the cost of defeating and reduce the benefits of bypassing safeguarding systems by applying techniques of design. Some of those techniques would be (i) providing better visibility, (ii) encouraging machine lockout, (iii) preventing unintentional faults for emergency stops, (iv) making safeguards easy to restore (Adams, 2001). Employees often consider machine safeguarding to be a luxury. This means that they only use the guards when they have time or when they are awaiting an inspection. They remove or disable the guards or protective devices for certain reasons, such as stress, a lack of knowledge, and production difficulties (Johnson, 1999). That study suggested paying attention to employees' training, providing positive personal changes as OHS professionals or supervisors' responsibilities, organizing an annual audit to ensure compliance with regulations and procedures, and enhancing management's commitment to improving unsafe situations. The reasons given by the people responsible when manipulations were found during a surprise control of Suva were to save time (22.8%), unsuitable machines (15.4%), poor ergonomics (15.4%), convenience (13.4%), ignorance/underestimation of risk (11.4%), habit (8.7%), they did not know (6.7%) and were ordered to or it was tolerated (6.0%). This information was gathered based on 219 controls and 149 replies (Zimmermann, 2007). The reinforcement of controls decreases the number of manipulations within enterprises. Respecting OHS rules is the employer's responsibility and workers should not have to change or remove protective devices (Zimmermann, 2007).

Chinniah (2009) identified manipulation of safeguards as the most common problem in 50 plants in Quebec's manufacturing sector since 2005 as a result of (i) underestimating the risks, (ii) lack of disciplinary action for people who bypass safety devices, and (iii) safety devices that hamper production. Schuster (2012) revealed that workers might defeat safety systems if safety systems are inconvenient or if the maintenance and operation are difficult when the safety systems are in place. Therefore, passive design and configurable design for the systems not only increase productivity, but also limit exposure to hazards and decrease incentives to bypass safety systems. Furthermore, another study identified defeating as one of the most common causes of accidents related to machinery in automated production. Safeguards are bypassed for faultfinding the equipment or providing sustainable production. Training employees, designing suitable safety measures by qualified designers, performing risk assessments during machine design are essential to avoid bypassing (Freedman, 2004).

Guards and protective devices were bypassed within the analysis of accident reports related to the moving parts of machines in Quebec retrieved from the CNESST database. Poor visibility, the frustration of removing and replacing guards during lubrication and maintenance, a rapid reaction to removing products that fall down, and avoiding downtime of equipment were identified as the reasons for bypassing (Chinniah, 2015a, 2015b). Safeguards in place and reinstated safeguards that are defeated should be checked during preventive maintenance. In addition, a specific control mode should be designed to permit the worker to reach into the hazard zone when the safeguards are disabled (Chinniah, 2015a). Those solutions are suggested to avoid bypassing-related accidents. ISO 12100 (2010) emphasizes that risk estimation should consider the incentive to bypass protective measures such as (i) safety measures are not easy to use, (ii) the safety measures are impractical; therefore, they are not accepted by users, (iii) safety measures slow down operations, and (iv) safety measures are not easily maintained. That standard requires the designers to take action to avoid circumventing protective measures; for instance, limiting access to safety devices and programming, minimal obstruction to view the production process, compatibility with the working environment, definition of a specific control mode and more.

Practical experience has demonstrated that guards and protective devices were bypassed because safeguards (i) must be removed or disabled repetitively due to the faults that disturb the working process, (ii) vibrate or rattle, (iii) are difficult to operate, (iv) are defeated easily, (v) obstruct the required view, and (vi) cause sequential failures after being tripped. New technological advances and safety engineering aspects protect safeguards from being defeated (Neudörfer, 2012). An operator's death occurred because he removed safety barriers during the installation task. Clear procedures for keeping the safety barriers in place and the connection of safety barriers to the control system are recommended to avoid bypassing or to stop the machine when safety barriers are open (Mattila et al., 1995). Charpentier and Sghaier (2012) revealed that protectors are disabled because of the poor design of protection systems and nonexistence of special operating modes for maintenance and troubleshooting. Roudebush (2005) found that safeguards need to be disabled or removed to perform tasks; therefore, administrative controls such as warning signs, safe working methods and training should be taken into consideration to ensure that safeguards are restored.

Gardner et al. (1999) investigated contributory factors to mechanical equipment injuries in small manufacturing businesses. Guards were often bypassed. Employees needed to remove the guards to carry out certain tasks. In addition, defeating safety devices was identified as a factor contributing to automation-related incidents that occur due to the reduction in downtime caused by production disturbances (Chinniah & Bourbonniere, 2006). Huelke et al. (2006) identified that defeating safety devices occurred in stationary machine accidents because of poor machinery ergonomics. However, the proportion of this is unknown in accidents.

Removing guards happens because management in enterprises allows such acts to occur (McConnell, 2004; Sherrard, 2007). Therefore, ensuring proper machine safeguarding, monitoring the use of safeguards (McConnell, 2004), and training and independent inspection of machines (Sherrard, 2007) are all suggestions to help decrease injuries and enhance productivity.

To conclude this subsection, according to the previous literature review, the incentives to bypass were extracted from 24 reviewed papers and other types of references. In addition, preventive measures are extracted from the 26 studies reviewed. Chapter 4 carries out an in-depth review of studies to analyze and categorize the possible incentives to bypass and the possible preventive measures for bypassing. Such information is useful to develop a tool for preventing bypassing.

2.2.3 Existing preventive tools for bypassing safeguards

The scientific articles directly related to the bypassing of safeguards are limited. According to the information achieved from the literature review, some of the solutions to prevent bypassing are related to machine designers and manufacturers. Although these solutions are intrinsic and more effective, they are not always applicable and the safeguards are therefore bypassed during the usage phase of the machine in the companies. During machine design, there is sometimes a gap between the designer’s knowledge and intentions and machine user’s needs and goals. In addition, ISO 12100 (2010) has indicated, “experience has shown that even well-designed safeguarding can fail or be violated”. It is difficult for designers to predict the varied work conditions that might exist in different enterprises. Moreover, designers do not have enough information related to corporate culture and psychological stress. Since the design of a safe machine is considerable and more effective in preventing unsafe behavior such as bypassing, several studies have emphasized the importance of considering behavioral issues at the design phase. Fogg (2009) presented an eight-step process for the persuasive technology design, which enables behavioral changes. Daniel Lockton (2013) developed and evaluated a toolkit for designers called “Design with Intent,” which influences environmental and social behavior change. It takes into account psychological and technical branches of knowledge at the design phase to understand and change behavior. In addition, Dan Lockton, Harrison, and Stanton (2010) applied the Design with Intent method developed for the designers to a “user behavior” problem. It illustrates that a user-oriented design process could influence more sustainable user behavior. Dan Lockton, Nicholson, Cain, and Harrison (2014) aimed to design systems that influence users’ actions to decrease the impact of the environment. This study developed ways to involve employees through a participatory design process to understand the role of their behavior in CO_2 emissions. Thus, such integration of technical and human factors could also be inspired, particularly for the machine design. Most of the time, companies import machinery, thus it is impossible for them to discuss these details during the design and machine building phases or to reach out to manufacturers before a first commissioning. During machine usage, operators sometimes work with old machines that do not comply with new design standards and regulations. Therefore, machine users bypass safeguards while working with machines. This thesis attempts to find a structured solution for this challenge at the machine use phase to prevent bypassing.

Within the references reviewed above, there are some suggestions to improve this problem based on the observations in specific industries or in small-scale research. Only three tools related to defeating are found. IFA (2011) developed an assessment matrix for the design phase of machines to evaluate the incentive to bypass (ITB). That tool was developed based on a limited number of benefits that may exist in the absence of protective devices (benefits identified by Apfeld et al. (2006)). However, in cases where the result of the assessment shows that bypassing has benefits, the IFA tool cannot solely determine whether bypassing will really happen. This tool can only indicate that an incentive to bypass exists for the tasks. More clarification is therefore required. This means that other factors such as organizational culture and psychological stress need to be taken into account. In addition, there is no sign in the study nor in the literature consulted that confirms that the assessment matrix has been either tested or validated. ISO 14119 (2013) published the IFA assessment matrix as an informative guide and recommended it to designers for evaluating the motivation to defeat interlocking devices. In addition, a checklist was designed for the purchase phase of the machine to minimize incentives to bypass protective devices (DGUV, 2013). Suvapro (2007) designed a general checklist to control the hazards of defeating, to define preventive measures for stopping manipulation. That checklist includes different parts: (i) new machine purchases, (ii) normal functions, (iii) specific functions and maintenance, (iv) human behavior, training and organization. These two simple checklists were only designed and suggested to companies without presenting the results of their performance. Moreover, the stop-defeating.org website was launched to help prevent defeating safeguards on machinery and share relevant discussions and bypassing-related information within companies. It also provides useful guides for manufacturers, suppliers and users.

To conclude, each of the above-mentioned tools contributes toward preventing bypassing in specific ways. However, they have some limitations, as has been explained. Furthermore, none of these studies have suggested a tool that deals with all possible aspects existing in the work environment, such as the machine itself or its safeguarding, corporate culture (e.g., lack of management commitment, workers' habits, and lack of disciplinary actions). All of these factors encourage a system-focused approach instead of a person-focused approach to tackle bypassing. This PhD research considered this broad scope of incentives.

2.3 Risk estimation tools

Section 2.2.3 shows that the studies related to tools to prevent bypassing are limited. Moreover, none of them assess bypassing based on probability levels that could give an idea of the importance of every bypassing situation identified on a machine. To add the probability levels to such a tool, this dissertation reviews how OHS-related risk estimation tools integrate risk parameters involving probabilities, and the number of levels for each parameter, as well as the number of risk levels. The following items were considered by this overview: informing the construction rules of an estimation tool, the choice of risk parameter, number of levels describing the parameters and the risk. Chinniah, Gauthier, Lambert, and Moulet (2011); Gauthier, Lambert, and Chinniah (2012) studied thirty-one industrial machine-related risk estimation tools, then compared and investigated their construction. Finally, they recommended several construction rules to design more accurate and appropriate risk estimation tools. For example, they proposed three to five levels for every risk parameter and no less than four risk levels as the optimal number of levels. Then, Chinniah, Gauthier, Aucourt, and Burlet-Vienney (2018) tested and validated six risk estimation tools with 25 machine safety experts. Those authors confirmed the effect of construction flaws in the architecture of the tools that could cause the selection of inappropriate or inadequate risk reduction measures. Burlet-Vienney, Chinniah, Bahloul, and Roberge (2015) designed and applied a five-step risk assessment tool for confined spaces. That proposed tool was applied to an accident investigation report retrieved from the Fatality Assessment and Control Evaluation (FACE) program on the National Institute for Occupational Safety and Health (NIOSH) database. They used that report as a case study. Then, the sufficiency of the tool was validated by 22 safety experts in 10 companies. In addition, Jocelyn, Chinniah, and Ouali (2016) developed a dynamic risk estimation process for machine safety which is a combination of dynamic risk identification and Logical Analysis of Data (LAD). Afterwards, the feasibility of the proposed process was discussed through its application to two accidents that occurred on conveyors.

An OHS risk estimation tool was developed for manufacturing systems. The performance of the proposed tool was evaluated by applying it to 20 hazardous scenarios and the results were compared with those of other risk estimation tools to confirm its ability (Moatari-Kazerouni, Chinniah, & Agard, 2015). Azadeh-Fard, Schuh, Rashedi, and Camelio (2015) introduced a new risk assessment matrix, which is called a three-dimensional matrix, because it is able to analyze the frequency, severity and preventability of an incident at once. That new risk assessment matrix was applied to a case study with real data.

Briefly, through this research, those studies have been the inspiration to develop a tool to estimate the probability of bypassing.

CHAPTER 3 RESEARCH APPROACH AND STRATEGY

This chapter more specifically describes the research problem and explains the research questions. The research methodology outlines how this research project contributes to answering the research questions by considering the hypotheses, as well as how it meets the research objectives. It clarifies the research process and presents the overall structure of the dissertation. Four dissertation articles (three scientific journal articles and one scientific conference paper) related to the objectives of this research are indicated in this structure.

3.1 Statement of the problem, research questions, and hypotheses

Chapter 2 presented a literature review in which a paragraph summarized or concluded every aspect of that literature at the end of every subsection of the chapter. According to the literature review, the findings of the references revealed that tampering with guards and protective devices has a wide dimension in the industry. Therefore, it is understood as a problem in organizations that needs to be paid attention to. This is despite the need to prevent or minimize bypassing-related accidents by eliminating or reducing the incentives to bypass in enterprises. Some studies (e.g. (Chinniah, 2015a; Dźwiarek, 2004; Hopkinson & Lekka, 2013)) only recommended several solutions to prevent bypassing; for instance, considering the special control modes, providing appropriate supervision, and promoting an awareness of bypassing. In addition, several studies (e.g. (DGUV, 2013; IFA, 2011; ISO 14119, 2013; Suvapro, 2007)) have been conducted to design a tool to prevent bypassing safeguards. The tools explained in Chapter 2 have focused on specific aspects of bypassing. None of them have recommended a tool for machinery safety that deals with almost all possible aspects of the workplace in the use phase of the machine. Therefore, the literature review in Chapter 2 sheds light on the gaps and the limitations of previous studies. Consequently, there is a need to develop a tool that helps enterprises, as the users of the machines, identify incentives to bypass to prevent bypassing, relying on a systematic approach.

The problem understood from the literature review leads to the following research questions:

1- How can OHS practitioners identify the existing incentives to bypass on their machine?

2- How can OHS practitioners find preventive measures to overcome bypassing on their machine?

3- How can one assess those incentives in order to avoid bypassing safeguards of the machine during the use phase?

The following hypotheses are considered to answer the research questions:

1- Having a tool that comprises the possible incentives to bypass, considering all elements of their work environment (e.g., procedures, equipment, operators, organization climate), will help OHS practitioners identify existing incentives to bypass on their machine at the use phase.

2- Providing an evidence-based list of preventive measures will equip the OHS practitioners to overcome bypassing,

3- Developing a usage-oriented version of the IFA matrix (initially dedicated to the design phase) built according to construction rules of risk estimation tools will allow the incentive to bypass to be assessed.

The main research objective is to design a tool for enterprises, as machine users, to prevent bypassing safeguards on machinery and to promote the use of safeguards in industry. The scope of this research is understanding that bypassing safeguards is a prevalent problem in industry, identifying the incentives behind bypassing to assess the probability of bypassing, presenting preventive measures to eliminate or reduce the incentives to bypass in three categories, including 1) technical, 2) organizational, and 3) individual factors, and finally, developing and testing an assessment tool.

Consequently, the originality of this research lies in:

1- Providing a wide scope review which has not yet been available in the literature. OHS professionals would benefit from a comprehensive review that addresses the bypassing of guards and protective devices on machinery.

2- Designing a bypassing-related assessment tool that is meant for the machinery use phase. The tool is able to estimate the probability of bypassing by evaluating the existing incentives to bypass safeguards, incentives that are related to 1) ergonomics, 2) productivity, 3) machine or safeguarding, 4) behavior and 5) corporate climate. The proposed tool is dedicated to OHS practitioners in enterprises dealing with machinery.

3- Designing the bypassing-related assessment tool by considering the construction rules of OHS risk estimation tools to generate more precise results than the three tools reviewed in the literature. Indeed, this tool defines the optimal number of levels proposed by Chinniah et al.

(2011) for two parameters defined in the assessment tool, as well as for the probability of bypassing.

4- Testing the proposed tool through bypassing-related accident reports, as well as by applying it to various machines in real companies to ensure its appropriateness. Unlike the tools reviewed where their performance is unknown, the performance of the tool was noted through the OHS practitioners' feedback.

3.2 Research design and approach of the research process

There is limited research available that is directly related to bypassing and preventive tools. According to (Creswell, 2013; Morse, 1994), qualitative research is useful and is exploratory when little research has been carried out on a concept. Therefore, qualitative research methods are employed in this PhD research because the topic is new and that approach allows for more creative writing. As such, Creswell (2013); Morse (1994) recommended qualitative approach for topics that have never been addressed with a certain sample or a focus group.

The design of the research process in order to translate the qualitative approach into practice is data collection, data analysis, and application in this dissertation. A mix of a literature review and case studies are conducted in this research. Sections 3.2.1 to 3.2.4 present in detail the methodologies applied in this research.

3.2.1 Construction of the literature review

Working with literature is an essential part of the research process. A literature review is a comprehensive review of studies previously published on a specific topic; therefore, it is instrumental in the process of research design. It helps generate ideas and it inspires, informs, educates and enlightens (O'leary, 2004).

Chapter 2 presented the full literature review associated with this thesis. As presented in that chapter, a review was conducted on standards and regulations, conference proceedings, and journal articles (e.g. technical and brief reports, accident-related papers). These documents were found by querying library databases (e.g. Compendex), and valid OHS websites (e.g. HSE[5]) using the following main keywords: bypassing, defeating, protective devices, guards, safeguarding, safety devices, interlocks, technical factors, organizational factors, human factors, incentives to bypass, reasons of bypassing, benefits of bypassing, machine safety. As the structure of Chapter 2 showed, the data gathered from the literature review are as follows:

1- Accident-related studies to show that bypassing is a prevalent problem in various sectors of industry.
2- The standards and regulations in the field of machine safety to find out the requirements related to the bypassing.
3- The incentives to bypass are explored as one of the prerequisites of the new assessment tool. This part answers the first research question.
4- The preventive measures of bypassing to eliminate or reduce incentives to bypass. This part is conducted to answer the second research question.
5- Existing tools related to bypassing are reviewed to identify the gaps and needs for designing a new tool to prevent bypassing. This part responds to the third research question.

As a part of the methodology, the raw data gathered in Chapter 2 was analyzed and classified to use it sufficiently, as it was planned for the development and the application of the tool. The results obtained are presented in the first article, as mentioned in Section 3.2.5 (the full text is available in Chapter 4).

3.2.2 IFA assessment matrix suggested by ISO 14119 and OHS risk estimation tools

ISO 14119, a safety-related standard at the machine design phase, suggested a method as an informative guide which incorporates the IFA assessment matrix. Chapter 2 presented the IFA assessment matrix (IFA, 2011) that was developed and suggested to designers. There is no result for testing or validating the framework in the literature. The IFA assessment matrix inspired the design of a new tool for machine users in this thesis. That matrix evaluates the incentive to bypass (ITB) a

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[5] Health and Safety Executive (HSE) is a body that supports organizations with advice, guidance, news, tools, publications, regulations, research related to occupational health, safety, and illness in Great Britain.

protective device by using the following Excel formula, which is explained in the following paragraphs:

=IF(COUNTA(B1:F1)>0,IF(AND(G1="Yes",H1="Yes"),IF(COUNT(I1:T1)<COUNTA(I1:T1),"present","low"),"high"),"")

The new tool adapts the formula that IFA (2011) used in its assessment matrix. The next paragraph explains how the IFA assessment matrix works. It evaluates the incentive to bypass (ITB) through answers to two closed questions and also an assessment of the benefits that may exist without the presence of protective devices.

The tasks and relevant modes of operation are defined for a machine (if a machine has more than one protective device, a new matrix should be dedicated to each protective device). Then, the matrix asks two questions: 1) is the task feasible in the determined mode of operation? and 2) can the task be performed without defeating? “Yes” or “No” options are offered to answer those questions. In the next step, a summary of the benefits (benefits existing without protective devices) in the HVGB report (Apfeld et al., 2006) is considered. Three possible entries, including “no benefit,” “minor benefit” and “significant benefit” are offered to determine whether there is a benefit to performing each task without the presence of protective devices. A benefit would be marked with one of those entries if the “Yes” option is selected for the first two questions noted above.
Finally, the IFA assessment matrix defines three levels, but this time for ITB:

- “Low”: no benefits for a task. Thus, there are no shortcomings in the design of a machine.
- “Present”: there is at least one minor or significant benefit for a task. ITB only indicates that an incentive to bypass exists for the tasks. It does not give further information and more clarification is therefore required.
- “High”: the task is not permissible in the operating mode or the task is impossible without defeating. Therefore, improvements are essential in the machine design.

In addition, the OHS risk estimations tools are studied (as explained in Section 2.3) because a review of some OHS-related risk estimation tools was considered relevant to inform the choice of risk parameters as well as the number of levels describing the parameters and the risk. Chinniah et al. (2011) studied 31 risk estimation tools related to the safety of industrial machines. The authors presented several construction rules. For instance, they recommended considering between three and five levels for every risk parameter and using no less than four risk levels as the optimal number of levels to achieve more reliable results. Such construction rules are considered in this study to define bypassing-related parameters and the number of levels for each parameter and, finally, to model a new tool.

The development of the bypassing-related assessment tool for the machine use phase is presented in the third article mentioned in Section 3.2.5 (the full text is available in Chapter 5).

3.2.3 Case study

A case study research was conducted in the test phase of the proposed tool in this research project. A case study research is a problem-based research to provide an empirical investigation and an in-depth analysis of the cases. The process of case study research provides a systematic approach to obtain a careful case analysis. In addition, information gathering takes a few hours, a few days, a few months or more (Hancock & Algozzine, 2016). In this research, the test phase of the tool is carried out in two steps.

First, testing the proposed bypassing-related assessment tool using accident reports as bypassing scenarios. Two of these scenarios are explained in Chapter 5 and detailed information related to the other three scenarios is available in Appendix B. The results of this step are presented in the third article mentioned in Section 3.2.5 (the full text is available in Chapter 5).

Second, the tool is tested by applying it to real machinery in various companies as case studies. To complete the test phase, four companies in the manufacturing sector were visited. During the visits, the research team visited their plants and existing machinery to have a better understanding of companies, as well as carry out a careful analysis. In addition, bypassing cases were observed and discussed with OHS practitioners. Since the proposed tool was developed for the OHS practitioners to assess the existing incentives to bypass and estimate the probability of bypassing, a meeting was held with OHS practitioners in each company. The instructions for applying the tool, as well as filling out the questionnaire, were explained to them step by step during the meeting. The application of the tool in the companies, as well as the results of the test, are presented in the fourth article, which was mentioned in Section 3.2.5 (the full text is available in Chapter 6).

3.2.4 Questionnaire

Using a questionnaire is a research method that has been proposed when designing a research process to collect required information (Creswell, 2013). The content of the questionnaire needs to be in line with the objectives of the research (Bell, 2014). In this PhD research project, the questionnaire was provided and applied to the test phase of the tool. The objective of the questionnaire was to receive the OHS practitioners' opinions and comments about the proposed tool. The questionnaire was designed as shown in Appendix G. The research team asked the OHS practitioners to fill out the questionnaire after applying the tool in their plants and to send their feedback back through the questionnaire to analyze the appropriateness of the tool. The results are presented in the fourth article mentioned in Section 3.2.5 (the full text is available in Chapter 6).

3.2.5 Research outputs: scientific publications

The following articles that have been published present the original research contributions conducted in this dissertation:

(1) Haghighi, A., Chinniah, Y., & Jocelyn, S. (2019). Literature review on the incentives and solutions for the bypassing of guards and protective devices on machinery. *Safety science, 111*, 188-204. doi: https://doi.org/10.1016/j.ssci.2018.07.010

(2) Haghighi, A., Jocelyn, S., & Chinniah, Y. (2019). Prerequisites for developing a machine safety bypassing-related assessment tool. 13 *th* International Conference on Industrial engineering and QUALITA Conference (CIGI QUALITA Conference 2019), Montreal, Canada.

(3) Haghighi, A., Jocelyn, S., & Chinniah, Y. (2019). A holistic assessment tool to estimate the probability of bypassing safeguards on machinery. *Safety Science, 120*, 561-574. doi: https://doi.org/10.1016/j.ssci.2019.08.009

(4) Haghighi, A., Jocelyn, S., & Chinniah, Y. (2020). Testing and improving an ISO 14119-inspired tool to prevent bypassing safeguards on industrial machines, *Safety*, *6(3)*, 42. doi: https://doi.org/10.3390/safety6030042

Figure 3.1 shows the Work Breakdown Structure (WBS) by activity. It provides an overview of the PhD research project. It includes the problem definition, the research questions, activities, and outputs concerning the scientific journal articles and conference paper.

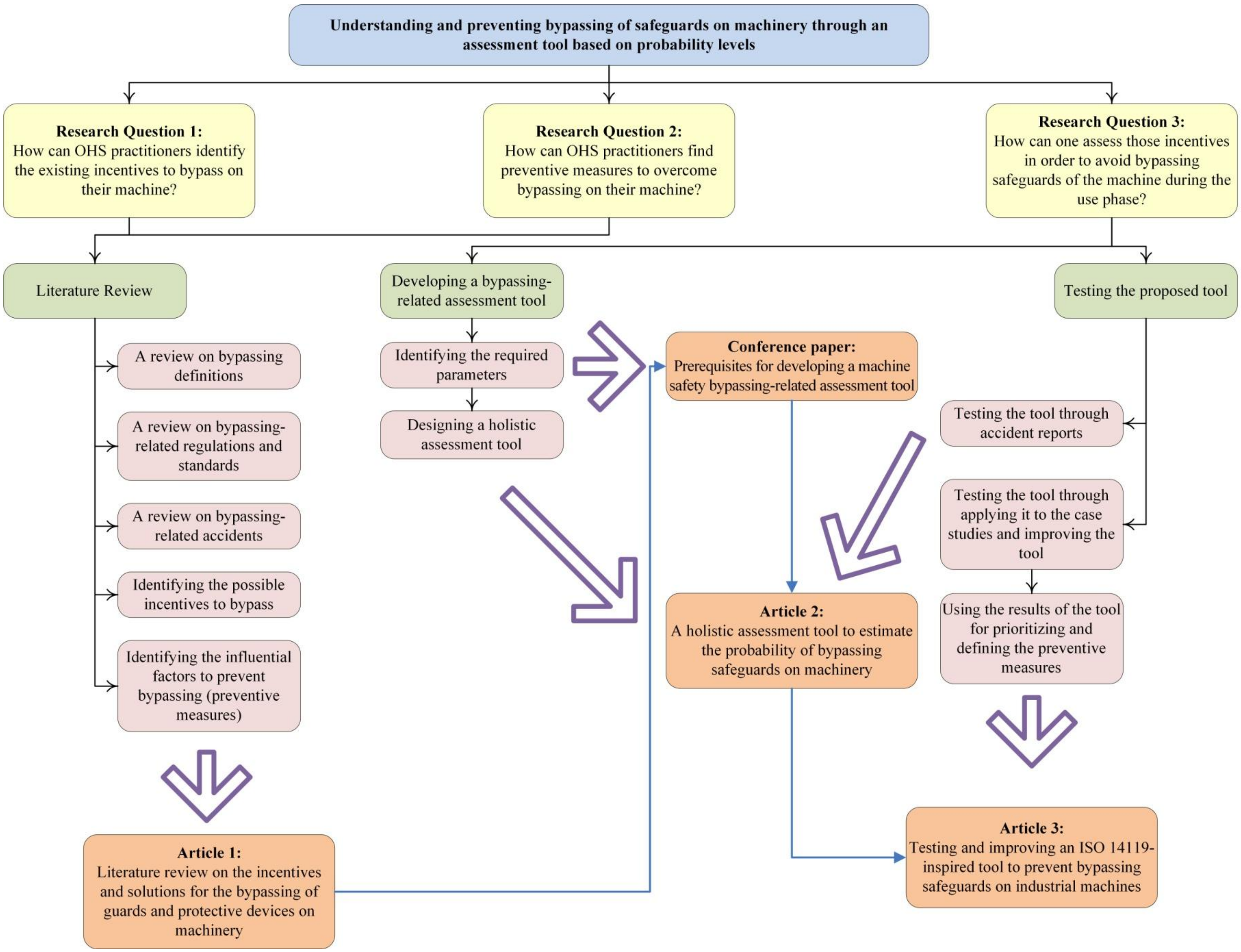

Figure 3.1 Work Breakdown Structure of the research project leading to scientific publications

CHAPTER 4 ARTICLE 1: LITERATURE REVIEW ON THE INCENTIVES AND SOLUTIONS FOR THE BYPASSING OF GUARDS AND PROTECTIVE DEVICES ON MACHINERY

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Abstract

Bypassing guards and protective devices on machinery can lead to serious and fatal accidents. The aim of this paper is to conduct a comprehensive review that sheds light on the definition of bypassing, related regulations and standards, workers' incentives to bypass, and possible solutions to overcome this issue. The review generated 72 incentives to bypass guards and protective devices and 82 solutions. Some of the most frequent incentives included the necessity to remove safeguards in order to perform activities (e.g. adjustment, troubleshooting, maintenance, and installation), a lack of visibility, failures and a lack of reliability of the safeguards. This literature analysis suggests classifying the incentives into five categories: ergonomics, productivity, machine or safeguarding, behavior, and corporate climate. The solutions, which are related to the design, manufacturing, and usage phases, are classified into technical, organizational, and individual factors. These are all factors that influence the prevention of bypassing. The review shows that there is a lack of an integrated tool to prevent bypassing. This paper serves as a foundation to develop such a tool, as well as to provide useful insights into the incentives for bypassing, as well as preventive solutions that could be used as a guideline for researchers and OHS preventionists.

Keywords: Bypassing, Machine safety, Guards, Protective devices, Incentives, Preventive solutions

4.1 Introduction

The aim of occupational health and safety (OHS) is to provide and to maintain a safe workplace. However, many workers throughout the world experience OHS-related risks. For instance, in the United States there were 155.9 million workers in 2014 (BLS, 2015). During their interventions on machinery, such as operation, maintenance or repair, workers may be exposed to different hazards, including mechanical, electrical, thermal, noise, vibration, radiation, material or contaminants, ergonomic and environmental hazards (ISO 12100, 2010). If not controlled, these hazards can cause injury such as cuts, burns, shocks, scalding, stress, tiredness, vascular disorders, insomnia, poisoning, musculoskeletal disorders and slipping (ISO 12100, 2010). To manage OHS-related risks, risk assessments and risk reduction measures (RRMs) are necessary. If RRMs were absent from an organization or were present but bypassed, workers may have been exposed to hazardous situations. In the hierarchy of RRMs described in the safety of machinery-risk assessment and risk reduction standard (ISO 12100, 2010), there are different types of measures for risk reduction. Those are, from the most to least efficient: (i) inherently safe design, (ii) safeguards, (iii) protective devices, (iv) information for use (warning signs, signals), (v) work method or procedures and (vi) personal protective equipment (PPE) (Figure 4.1).

In half of the enterprises in Switzerland, protective devices on machinery have been bypassed (Zimmermann, 2007). Approximately 37% of all protective devices on metalworking machines in Germany have been bypassed (Apfeld, 2010; Apfeld et al., 2006; IFA, 2011). In their Analytic Hierarchy Process-based decision making method for selecting safety devices, Caputo, Pelagagge, and Salini (2013) identified "tampering avoidance" as one of the rating criteria for the selection of safety devices. The possibility of removing, bypassing, disassembling, deceiving, sabotaging, or rendering a device as ineffective are evaluated in this criteria. They concluded that a safeguard should satisfy effective protection and not impair work or decrease productivity. A safeguard should also be cost-effective during its lifecycle, difficult to defeat, and not cause any additional hazards. Some accidents have occurred due to protective measures bypassed by the manufacturer (Doucet & Brassard, 2010). This fact is worrisome, since employers trust manufacturers with the installation and other phases of machine design and building. Hence, Doucet and Brassard (2010) suggested revising the regulation, at least in Quebec, to extend manufacturers' liability. Yasui, Obata, Fukui, Matsumoto, and Fujita (2010) developed the "third generation interlock switches with a solenoid lock" that meets "defeat prevention" as a key requirement in ISO 14119 to keep workers safe even when a failure has occurred. Haukea, Nabera, Bömera, Koppenborga, and Huelkea (2015) tested the ability to crawl underneath and bypass a 3D electro-sensitive protective device. They determined that the maximum distance greater than what is stated in (ISO 13855, 2010) between the detection zone and fixed elements such as a wall or floor is not justifiable. Finally, the International Social Security Association (ISSA) was carrying out a project on bypassing that stresses the importance of the problem worldwide, namely in Austria, Germany, Italy, and Switzerland (Apfeld, 2010).

The previous references demonstrate the importance of the issue of bypassing. Certain tools exist to help overcome this issue: an assessment matrix that assesses the incentives to bypass protective devices (IFA, 2011), a checklist for machinery purchase with the minimum incentives to bypass protective devices (DGUV, 2013), and a checklist to stop the manipulation of protective devices, which enables the hazards of bypassing to be controlled (Suvapro, 2007). Nevertheless, none of these studies have suggested a holistic tool that deals with aspects other than machinery and safeguarding to explain bypassing and ways to prevent it. In order to provide a holistic tool in the future, this paper aims to conduct a comprehensive review that sheds light on the definition of bypassing, related regulations and standards, incentives to bypass, and possible solutions to overcome this unfavorable behavior. The holistic tool would help eliminate or reduce bypassing of guards and protective devices by addressing not only incentives related to machinery and safeguarding, but also incentives regarding ergonomics, productivity, behavior and corporate climate aspects found in an analysis of the literature review. The tool would also include solutions to prevent bypassing, taking into consideration the three kinds of preventive solutions found in the literature: technical, organizational, and individual.

Although this study has attempted to encompass a wide breadth of documents related to the problem of bypassing, it cannot claim to be fully comprehensive.

To provide some context and background for the reader, after presenting the method in Section 4.2, Section 4.3.1 explores some definitions of bypassing, and Section 4.3.2 reviews standards and regulations on the subject. To stress the importance of the bypassing issue, Section 4.4 presents an analysis of articles on accidents and statistics of injuries and fatalities related to the bypassing of guards and protective devices on machinery. To obtain a deep understanding of the reasons that lead to bypassing, Section 4.5 explores the incentives to bypass. Section 4.6 reviews solutions to prevent bypassing. Section 4.7 conducts a discussion and an analysis on the findings from the literature. Finally, Section 4.8 concludes the paper.

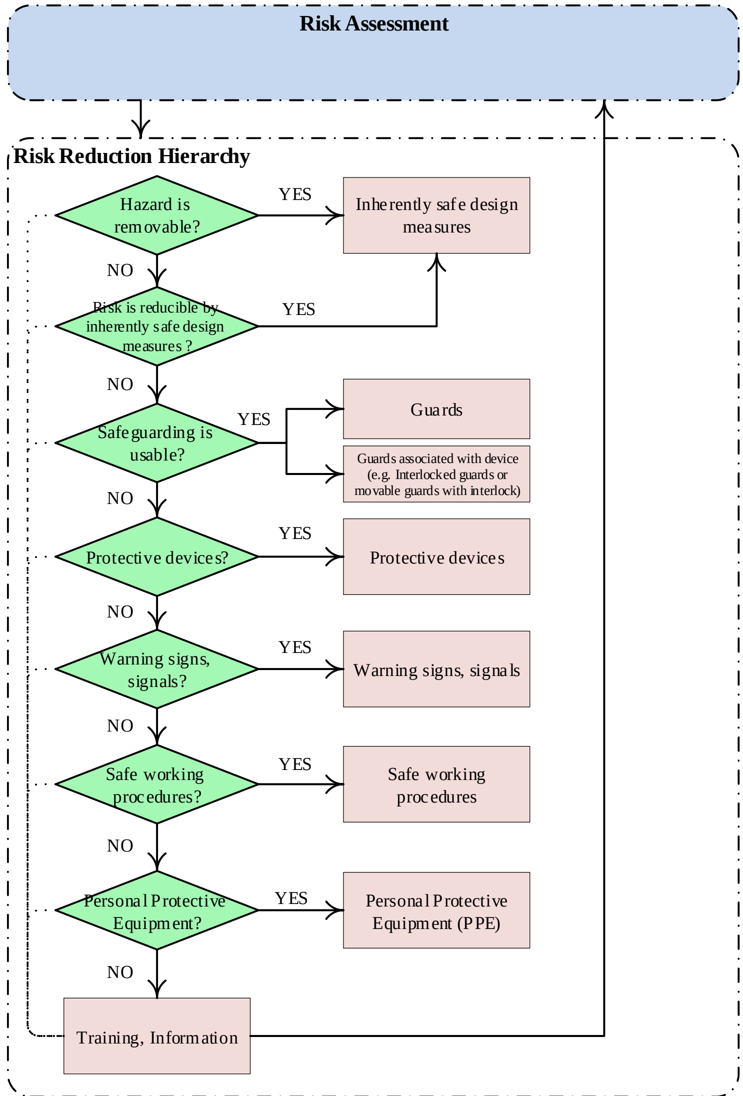

Figure 4.1 The hierarchy of risk reduction methods inspired by ISO 12100 (2010) and adapted from (Giraud, 2009)

4.2 Method

In order to achieve the goal of this paper, the bypassing of guards and protective devices was extensively reviewed in the existing literature. This review includes standards and regulations, conference proceedings, and journal articles (e.g. technical and brief reports, accident-related papers). These documents were found through querying library databases (e.g. Compendex), and valid OHS websites (e.g. HSE[6]) using the following main keywords: bypassing, defeating, protective devices, guards, safeguarding, safety devices, interlocks, technical factors, organizational factors, human factors, incentives to bypass, reasons of bypassing, benefits of bypassing, machine safety. The primary data for this review was gathered from accident-related studies in which bypassing was identified as one of the contributing factors in the occurrence of severe injuries and fatalities. Afterwards, an analysis of documents regarding bypassing narrowed down to incentives to bypass and associated preventive solutions. As each document was reviewed, the extracted information was further classified in tables as references, incentives for bypassing, and possible solutions to prevent bypassing of safeguards. By providing a classification scheme of incentives to bypass and potential solutions to prevent bypassing, our contribution is:

- establishing a reference repository on bypassing in order to present a valuable source and guide for researchers and OHS preventionists,
- providing a good foundation for designing the holistic tool described in Section 4.1 for future research.

4.3 Bypassing

4.3.1 Definition

Despite the existing regulations and standards emphasizing the use of RRMs, accidents happen due to the absence of safety measures or the fact that they are bypassed. “Bypassing means neglecting or ignoring usually intentionally and defeating means undoing or destroying,” states Webster’s International Dictionary (Babcock Gove, 1993). In the literature, documents in German, English, and French were consulted. Authors have used the following terms as synonyms for bypassing (*Contournement in French*): Neutralization, Tampering, Cheating (in French: *Neutralisation*, *Trafiquer*, *Frauder*), Overriding, Manipulation (in English, French, and German), Circumventing, Removing, Sabotage, Deceiving, Disassembling, Making ineffective, Deactivating, Disengaging the guards, Violation, Noncompliance, Defeating, Derogation, Disabling. Moreover, muting is a kind of

[6] Health and Safety Executive (HSE) is a body that supports organizations with advice, guidance, news, tools, publications, regulations, research related to occupational health, safety, and illness in Great Britain.

bypassing in which safety measures are bypassed to finish an operation within a certain time limit and it has to become effective again automatically (Neudörfer, 2012). The existing definitions of bypassing in the standards and literature are shown in Table 4.1.

Table 4.1 Bypassing definitions

Definitions of bypassing	Reference
"Defeat is an action that makes interlocking devices inoperative or bypasses them with the result that a machine is used in a manner not intended by the designer or without the necessary safety measures. Defeat may be carried out manually or by applying tools."	(ISO 14119, 2013)
"Rending inoperative the protective devices with the result that a machine is operated in a manner not intended by the designer or without the necessary safety measures."	(Apfeld, 2010; Apfeld et al., 2006; IFA, 2011)
"Circumventing the detection zone means reaching the hazard zone without actuation of the protective device by passing over, under or to the side of the detection zone"	(ISO 13855, 2010)

Table 4.2 gives some examples of bypassing situations.

Table 4.2 Examples for bypassing of guards and protective devices

Risk Reduction Measures (RRMs)	Examples of bypassing
Guards	-A sewing needle wedged in the "on" button of fully automated circular knitting machine so that the machine always continues to operate when the safety gate with interlock switch was open. (NIOSH, 2004) - In a molding machine, the process had been automated and to reach the robot into the mold zone at the end of each cycle, the guards had to be remained open. (Chinniah, 2015a, 2015b)
Protective devices	-Attaching pieces of metal permanently to bypass the proximity sensors. (Chinniah, 2015a, 2015b) - The machine was interrupted frequently because of dust generated due to bricks production. Therefore, a safety light beam was disabled. (Chinniah, 2015a, 2015b)

Since the previous definitions have been limited to the bypassing of protective devices only, we will develop the scope of the term "bypassing" for the second and third types of risk reduction measures (i.e. guards and protective devices). Therefore, the following comprehensive definition, rather than the above-mentioned definitions, is presented for the concept of "bypassing":

"Bypassing is an action that neglects the guards and protective devices or renders them nonoperational such that a machine is operated in a way that is unlike the designer's intention; the tasks are carried out in a manner that is non-compliant with the requirements or instructions or without required protective measures."

4.3.2 Standards and legal requirements dealing with bypassing

"On average one third of all protective devices are temporarily or constantly manipulated" (Apfeld et al., 2006; Lüken et al., 2006). Because of the importance of this issue, some regulations, non-international standards, as well as international standards published by the International Organization for Standardization (ISO) take it into account, as described in Table 4.3.

Table 4.3 Legal and standard requirements related to bypassing

Requirements, Legal responsibilities	**Reference**
-The "possibility of defeating or circumventing protective measures" has been identified as one of the aspects to be considered during risk estimation. It should be taken into account to implement guards and protective devices. - Obtaining the maximum functionality of the machine is momentous. Thus, the possibility of defeating guards and protective devices will increase if they inhibit the intended use of machine and are difficult to use.	(ISO 12100, 2010)
-To lessen any incentive to defeat interlocking devices, the interference with operation and other activities during life-cycle of machine shall be minimized to prevent defeating.	(ISO 14119, 2013)
-Guards and protective devices must be difficult to bypass or make inoperative. They must not restrict visibility of the production process. Moreover, guards and protective devices must enable limiting the access to the work area during the interventions, such as carrying out the installation, tool exchange or maintenance without the need to defeat the guards or protective devices.	(Le parlement européen, 2009)
-Article 49- 2°: Workers must apply the required measures to protect their health, safety, and physical integrity. -Article 51: The employer must consider the required measures to protect the health and ensure the safety and physical integrity of the worker. (3°) shall ensure that the methods and techniques used to carry out the work are safe with no effect on the health of the worker. -Article 236: Under this article, every person who violates the law or regulations or refuse to adhere to a decision or an order or encourage others to do so, is liable and commits an offense and should pay a fine.	(LSST, 2017)

Table 4.3 Legal and standard requirements related to bypassing (continued)

Requirements, Legal responsibilities	Reference
-Article 182: The machine shall be equipped with at least one guards or protective devices to control the dangerous zone and to render it inaccessible. -Article 189.1: The machine must be equipped with a specific control mode and the other control modes should be inoperative when it is necessary to displace or remove a guard or to defeat a protective device during performing the adjustment, learning, faultfinding, cleaning into the hazardous zone whereas the machine should remain wholly or partly in operation.	(RSST, 2017)
-"The protective effect of the two-hand control device shall not be easily defeated." -"The use of one hand alone", "the use of the hand and elbow of the same arm", "the use of the forearm or elbow", "the use of possible combinations of one hand and/or other parts of the body (e.g. knee, hip)", "blocking one control actuating device and/or the use of simple aids (e.g. bridges, cords or tapes)" are the ways of defeating which shall all be considered to avoid entering into the hazardous zone.	(ISO 13851, 2002)
-The employer is responsible to respect OHS rules. S/he has a key role in the performance of protective devices. S/he should ensure that the efficiency of protective devices is never hindered. -Tolerating the manipulation of protective devices by the employer is punishable and the manipulation has been considered as a serious negligence. Furthermore, the workers are strictly prohibited from modifying or removing protective devices. -Any accident due to the bypassing can lead long-term legal troubles.	(Zimmermann, 2007)
One or more methods of machine guarding shall be provided to protect the operator and other employees in the machine area from hazards.	(OSHA-1910.212)
The circumvention of the electro-sensitive protective equipment to reach into the danger zone shall be avoided.	(ISO 13855, 2010)
That study emphasized that the law prohibits tampering with protective devices or working on machines that do not have these elements. Superiors should not tolerate such practices.	(Suvapro, 2007)
In general requirements, it mentions that guard and protective devices shall not be "easy to bypass".	(CSAZ432, 2016)

Analyzing Table 4.3 demonstrates that standard requirements are addressed for machine designers. On the other hand, regulations give requirements to workers and employers in addition to designers. That fact indicates that bypassing is a substantial issue that should be considered during the whole life-cycle of machinery by designers, manufacturers and finally, enterprises as end users. The latter is necessary to consider during the design and building of a machine, since machinery is operated by users. Kabe (2010) proposed a new thought called "Safety Service Engineering". It promotes the users' satisfaction by:

- considering the needs of users at the design phase,
- developing rules between machine builders and users,
- improving man-machine interactions during machine operation to avoid defeating the problem.

That three-point statement inspires the analysis of the documents reviewed with regards to the incentives to bypass (Section 4.5) and the solutions to prevent bypassing (Section 4.6). These solutions are measures to reduce the risk of accidents related to bypassing. Section 4.4 provides examples of accident statistics stressing the contribution of that issue in the injuries and fatalities of workers.

4.4 Accidents and statistics of injuries and fatalities related to bypassing

A review of 22 articles was conducted to analyze papers dealing with accidents related to machinery. The articles analyzed accidents in different countries in various industrial sectors and systems. They revealed that bypassing is one of the contributing causes of the accidents analyzed (Table 4.4). According to these investigations, bypassing represents a significant portion of accidents and is a prevalent problem in the occurrence of accidents. Furthermore, Freedman (2004) asserted that bypassing safeguards is one the most common contributing factors in accidents that occur in automated production related to machinery. Samant et al. (2006) stated that from 1995-1997, machine guards were not used in two-thirds of amputation incidents in woodworking and metalworking industries in Minnesota, USA.

Table 4.4 Analysis of the reviewed articles on accidents and statistics of injuries and fatalities related to bypassing on machinery

Reference	Country	Sector, Domain	Machine, system	Period	Main results
(Vautrin & Dei-Svaldi, 1989)	France	Production	Automated systems	1983-1988	Fifty-four accidents were analyzed and it noted that the level of manipulation of protective systems must be taken into account in the evaluation of preventive measures.
(Järvinen & Karwowski, 1993)	U.S.	Advanced manufacturing systems	Computer-integrated man ufacturing systems (CIMS)	-	Eighty-five accidents were analyzed and it detected problems related to safeguarding. In 40% of the cases, safeguards were defeated or removed.
((Edwards, 1993) cited in (Backström & Döös, 2000))	Great Britain	Computer controlled manufacturing plant	Automated systems	1987-1991	In 16% of accidents, safeguards were bypassed or removed.
(Backström & Döös, 2000)	Swedish	Manufacturing industry	Automated production	1988-1990	-Problems in 76 automation accidents in 21 worksites were: (i) safeguard failure, (ii) safeguards are not used (remove, circumvent, defeat, decouple or failure to activate), (iii) safeguards do not stop all machine movements in the hazardous zone, (iv) safeguards are not able to provide full protection (safeguards with too limited range). - Non-use of safeguards was involved in 35 cases (54%) including stop device and in 16 cases (47%) excluding stop devices. - Non-use of safeguarding cases include: (i) “safeguard removed”, (ii) “safeguard seldom used”, (iii) “a lot to do or production disturbances”, (iv) “inexperience”, (v) “do not know”.

Table 4.4 Analysis of the reviewed articles on accidents and statistics of injuries and fatalities related to bypassing on machinery (continued)

Reference	Country	Sector, Domain	Machine, system	Period	Main results
(Shaw, 2010)	UK.	-	Machinery	2002-2007	The contributory factors in 100 reviewed incident reports were: (i) insufficient design, (ii) lockout failures, (iii) flaw in fault reporting or maintenance, (iv) bypassing of safety system.
(Charpentier, 2005)	France	-	Automated machinery	20 years	In 45% of 457 automation accident reports from the EPICEA[7] database, despite the presence of guards and safety devices, the accidents stemmed from: (i) implementing and utilizing improper guards (35%), (ii) bypassing of guards (30%), (iii) failure of guards (15%).
(Chinniah, 2015a, 2015b)	Quebec, Canada	Manufacturing and processing	Moving parts of machinery	1990-2011	- The contributing causes of accidents were: (i) easy access to moving parts of machinery, (ii) absence of safeguarding, (iii) lack of lockout procedures, (iv) inexperienced workers, (v) insufficient supervision, (vi) poor machine design, (vii) existing unsafe working methods, (vii) absence of risk assessment, (ix) bypassing safeguards. -Fourteen of 106 accidents were related to remove or to bypass the guards and protective devices.
(Dźwiarek, 2004)	Poland	Polish industry	Machine control systems	1996-2002	Seven hundred accidents were studied and 54 of them were associated with the malfunctioning of machine control systems. Unsuitable activities which are carried out by operators and caused the accidents, were: (i) inadequate response to a sudden event, (ii) utilization of working procedures which do not cover safety

[7] EPICEA: Prevention studies through computerisation of investigative reports on work-related accidents (*Etudes de prévention par l'informatisation des comptes rendus d'enquêtes d'accidents du travail*)

Table 4.4 Analysis of the reviewed articles on accidents and statistics of injuries and fatalities related to bypassing on machinery (continued)

Reference	Country	Sector, Domain	Machine, system	Period	Main results
					requirements, (iii) try to defeat protective systems.
(Mattila et al., 1995)	Finland	Production applications	Flexible Manufacturing Systems (FMS)	1985-1990	-Eight fatal accidents involving automated machines were analyzed. The factors contributing to these accidents were: (i) improper or defective, not installed, or switched off safeguards, (ii) access to danger zone easily, (iii) crushing by a part of a machine or a workpiece, (iv) confusing controls, (v) inadequate knowledge about that how the machine works or what coworkers are carrying out, (vi) not being able to identify hazards, (vii) not being able to eliminate hazards. -Thirty-five incidents during 10 years involving FMS were studied. In one case at loading/unloading station; the worker entered into the operation zone because the safeguard was not used or because of human error.
(Gardner et al., 1999)	Australia	Manufacturing businesses	Mechanical equipment	-	-The contributory factors of injuries investigated in 35 small manufacturing businesses were: (i) not following safe working procedures, (ii) lack of or insufficient guards, (iii) poor design and poor condition of the machine. - Eighty-seven incidents were reported, guards or lockout were bypassed (in 3 cases), guards were removed (in 2 cases) or set incorrectly (in 2 cases).
(Chinniah & Bourbonniere,	Quebec, Canada	-	Automated systems	2003 2004	The reports of accidents related to the automated systems revealed by CNESST[8] were examined. Several

[8] "*Commission des normes, de l'équité, de la santé et de la sécurité du travail*" in Québec is an organization that sets rules for working conditions, handles pay equity issues, and is Quebec's workplace safety board (reference: http://montrealgazette.com/news/local-news/csst-and-others-to-merge-and-form-cnesst)

Table 4.4 Analysis of the reviewed articles on accidents and statistics of injuries and fatalities related to bypassing on machinery (continued)

Reference	Country	Sector, Domain	Machine, system	Period	Main results
2006)				2006	contributing factors that are identified: (i) unintended start-up or machine movement, (ii) inadequate or inappropriate safeguarding, (iii) insufficient training for workers, (iv) underestimating the risk, (v) defeating existing protective devices, (vi) advances of automated systems. In addition, a human error such as (i) miscommunication between workers and coworkers, (ii) incorrect use of safeguards, (iii) bypassing of safety devices, (iv) guard removal, (v) program modifications in the electronic programmable safety devices is a potential factor that contributes to automation-related incidents.
(Pratt & Hard, 1998)	U.S.	Agricultural production industry	-	1990-1996	-The work-related fatalities investigation conducted by NIOSH[9] State Fatality Assessment and Control Evaluation (FACE) were analyzed. Not using the available safety equipment at the workplace (16, 3,4%), inaccessibility to the safety equipment or PPE at the workplace (51, 42.9%), and not controlling hazardous energy (e.g. lockout) (32, 26.9%) were identified as three of the injury risk factors. - In a small number of cases in the FACE investigations, protective devices were bypassed, however, those circumstances were not completely explained.
(Apfeld, 2010;	Germany	Metalworking	-	-	-Thirty-seven percent of protective devices were

[9] The National Institute for Occupational Safety and Health (NIOSH) in the United States

Table 4.4 Analysis of the reviewed articles on accidents and statistics of injuries and fatalities related to bypassing on machinery (continued)

Reference	Country	Sector, Domain	Machine, system	Period	Main results
Apfeld et al., 2006; Lüken et al., 2006)					bypassed (14% permanently and 23% temporarily) based on returning 940 questionnaires and investigating 202 machines. -Twenty-five percent of the machine-related accidents happened because of defeating protective devices. According to this percentage, there were more than 10000 accidents and 8 deaths due to bypassing in Germany in 2008. - Thirty-four percent of companies were affected by bypassing. -Fifty-one percent of machines were potential sources of accidents due to bypassing.
(KANbrief, 2003)	Germany	-	-	-	OH&S experts have observed that position switches on safety gates have been defeated in their site visits, which had dangerous consequences, such as serious injuries and death.
(Charpentier & Sghaier, 2012)	France	-	Industrial robots	1997-2010	Thirty-one accidents on the EPICEA database were studied. In 8 accidents the protectors were disabled temporarily or permanently.
(Zimmermann, 2007)	Switzerland	-	-	2007	-In 50% of enterprises, protective devices of machinery and automatic facilities are manipulated, which caused serious injuries or fatal accidents. -Suva[10], in a study in 300 enterprises in Switzerland in 2007, showed that 37% of respondent companies admitted that they deactivated the protection devices.

[10] Suva is an organization in Switzerland that works in the areas of prevention, insurance, rehabilitation, and workplace safety in companies.

Table 4.4 Analysis of the reviewed articles on accidents and statistics of injuries and fatalities related to bypassing on machinery (continued)

Reference	Country	Sector, Domain	Machine, system	Period	Main results
					-Eighty percent of respondent companies underestimate the risk of accidents.
(Chinniah et al., 2007)	Quebec, Canada	Plastic industry	Injection molding machines	-	Incidents occurred because of (i) entering into a dangerous zone through, around, under, over guards, (ii) removing or bypassing guards and protective devices, (iii) accessing the machine to remove jamming, (iv) not using lockout/tagout procedures, (v) failure of the machine, (vi) being unaware of the machine and its hazards, (vii) using machines with guards insufficiently.
(Huelke et al., 2006)	Germany	-	Stationary machine	1996 - 2000	-The causes of accidents in HVBG[11] statistics were extracted: (i) inadequate or lack of safeguarding, (ii) bypassing of safety devices intentionally, (iii) devices are operated out of their specifications, (iv) software error with temporary faults, (v) safety devices are designed or installed incorrectly, (vi) environmental troubles with temporary faults, (vii) existing operational faults inadvertently because of poor usability of operating and safety devices, (viii) accidental faults in equipment hardware that were unrecognized.
(Hopkinson & Lekka, 2013)	UK	Engineering, plastics and	Computer Numerical	2007-2010	Eleven cases out of the 23 accidents from the COIN[12] database and 15 cases of 20 accidents from the

[11] Hauptverband der gewerblichen Berufsgenossenschaften (HVBG) is the German Federation of Institutions for Statutory Accident Insurance and Prevention.

[12] COIN (Corporate Operational Information System) database holds accident and incident and HSE (Health and Safety Executive) enforcement and inspection data

Table 4.4 Analysis of the reviewed articles on accidents and statistics of injuries and fatalities related to bypassing on machinery (continued)

Reference	Country	Sector, Domain	Machine, system	Period	Main results
		woodworking industries	Control (CNC) machines		RIDDOR[13] database were related to the defeating of interlocks on CNC machines.
(D. L. Parker et al., 2009)	USA	Metal fabrication	-	2006-2007	Bypassing safeguards were observed in 19% of 40 metal-fabrication businesses at baseline.
(Samant et al., 2006)	USA	Metalworking	-	16 months since April 2004	This study indicated that machine safeguarding was insufficient by evaluating 824 machines in 40 small metalworking businesses in Minnesota because of the high rate of their non-fatal injuries.
(Chinniah, 2009)	Quebec, Canada	Manufacturing	-	Since 2005	Fifty factories in the manufacturing sector had been visited and bypassing guards and protective devices was observed as one of the most common problems related to machine safety that causes machine-related accidents. Therefore, better use of machine safeguarding was identified as one of the improvement actions for machine safety in Quebec.

[13] The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) requires employers, the self-employed, and a responsible person to record and report serious work related accidents, occupational diseases, and near misses in Northern Ireland.

4.5 Incentives for not using or bypassing guards and protective devices

A common problem when accidents occur is that guards and protective devices are bypassed. This has drawn organizations' and researchers' attention in order to determine what is behind the bypassing and to understand that it is not only a result of operator failure. To solve a problem, one needs to understand its reason for existing. Accordingly, it is crucial to determine the incentives for bypassing, rather than to identify the people responsible for these risky acts. Therefore, documents were reviewed to gain a better and deeper understanding of the incentives for bypassing guards and protective devices.

The HVBG report was the first report to present trustworthy statistics and information on the bypassing of protective devices (Apfeld et al., 2006). It listed the benefits (e.g. faster work process) in bypassing protective devices. Later, IFA (2011) applied these incentives to develop its assessment matrix for designers. This tool is available as an Excel spreadsheet for evaluating the incentives of bypassing in practice. Apfeld et al. (2006) concluded that automatic, setting up or installing, and readjusting modes are most likely to be tampered with and that the manipulation of safeguards usually occurs during troubleshooting activity. Other studies provided an overview of this research (Apfeld, 2010; Lüken et al., 2006). Lüken et al. (2006) revealed that tampering often happens in set up, troubleshooting, reconstruction, and automation modes, while Apfeld (2010) identified that manipulation is often detected in troubleshooting machinery, setting, troubleshooting organizational work, tool exchange, cleaning, maintenance, and adjustment modes. Hopkinson and Lekka (2013), in phase 2 of their research, found that in hybrid machines such as semi-CNC machines, interlocks are defeated more often in setting and proving, deburring, drilling, swarf removal, removing or replacing collet, finishing and polishing, and machining inside pipes.

Tochio et al. (2010) stated that having safe machinery is not enough to reduce work-related accidents. Operators might work with a machine in an improper manner, such as disabling the protective devices, despite existing residual risks, if they are not aware of the machine hazards. In addition, operators may defeat the guards and interlock switches when the machine becomes troublesome to use (e.g. a machine might be difficult to access or it may stop frequently) because designers may have ignored operators' comments during the design phase. Communication of the risks between designers and users would, therefore, improve these situations. Moreover, CE marking on machines does not mean that the bypassing will not happen when the machine is operating (IFA, 2011), because Apfeld et al. (2006) showed that 50% of machines possessing a CE mark were bypassed.

Chinniah et al. (2007) showed that machine safeguarding is one method for mitigating the risks. However, in reality, there are different situations that cause potential hazards in workplaces. For example, companies in one country may import machinery from other countries that have different safety regulatory requirements. Other enterprises purchase and have to operate the machines that may have improper safeguarding. In some cases, engineers upgrade and customize the machines without having enough knowledge about risk assessment and machine safeguarding. Finally, existing protective devices, which may be bypassed for various reasons, are not reinstated (IFA, 2011).

Zimmermann (2007) did an unplanned inspection and identified time-saving (22.8%), unsuitable machine (15.4%), and poor ergonomics (15.4%) as the most probable manipulation incentives. Hopkinson and Lekka (2013) carried out research in two phases to identify why operators defeat the interlocks on CNC machines among a small number of small and medium-sized enterprises (SMEs). They explored predisposing (e.g. individual characteristics), reinforcing (e.g. reward and punishment) and enabling (e.g. environment and system) factors to understand behaviors that influence operators to defeat interlocks. Enabling factors were the most prevalent motives cited for bypassing. Poor machine design, lack of visibility, impaired accessibility to the tools or the job and poor usability were identified as the most frequent reasons cited for bypassing interlocks pertaining to enabling factors. Adams (2001) stated that cost-benefit models can help human factor experts analyze why workers bypass safeguarding.

Table 4.5 summarizes the incentives described in the articles reviewed on bypassing guards and protective devices. The "code" column lists the number of incentives mentioned in the articles. The incentives are coded starting with I (first letter of Incentive). The next column presents the incentives. Even though some of the incentives may appear to be similar, we have listed them without eliminating possible redundancies in the findings. The lack of detail in some reviewed references prevented us from confirming if some incentives were totally similar. On the other hand, identical incentives may appear in different papers, with a variety of words used to express the same thing. One example is "poor visibility," "lack of observability of the working process," "impaired visibility," etc. The words and statements are therefore grouped under a unique statement that encompasses all statements (see the third column). The "N" and "%" columns illustrate the absolute and relative frequency of the incentives mentioned in the documents.

Table 4.5 Summary of the incentives for bypassing guards and protective devices in the reviewed articles

Code	Incentives for bypassing	Unique statement (answering why)	N	%
I1.	There was too much work to do (Backström & Döös, 2000)	There is a lot of work to carry out.	1	0.595
I2.	Operator had to reach into the hazardous zone several times to perform his/her task (Backström & Döös, 2000)	Reaching several times into a hazardous zone to do the work.	1	0.595
I3.	"Safeguard meant extra work" (Backström & Döös, 2000)	Using safeguards is an extra work.	1	0.595
I4.	Using safeguard takes time (Backström & Döös, 2000)/ Using safety devices cause extreme delays before starting the operation (KANbrief, 2003)/ Removing or replacing the guard needs a long time (Adams, 2001)	Using safeguards is time-consuming.	3	1.786
I5.	Operator was too novice to do the job (Backström & Döös, 2000)	Operators are inexperienced.	1	0.595
I6.	Inexperienced operator believed that the machine was safe (Backström & Döös, 2000)/ Operator did not think that operating a machine which was bypassed was unsafe (Apfeld et al., 2006)/ Operators thought that using safeguards are unnecessary (Hopkinson & Lekka, 2013)/ Guards are "luxury items", therefore, they only used guards when they have time, the manager advised them or they were waiting for an inspection (Johnson, 1999)	Operators feel machines are safe without safeguards, and using them is unnecessary.	4	2.381
I7.	Operator was not familiar with the hazards of not using safeguards (Backström & Döös, 2000)/ Workers were not aware of the possible risks (KANbrief, 2003)/ Workers did not take into account that defeating of protective devices is a hazard and they did not have negative thinking towards bypassing (Apfeld et al., 2006)/ Workers had limited awareness of risks and they did not perceive the "true risk" of defeating (the severity and the probability of the consequences) (Hopkinson & Lekka, 2013)	There is a lack of knowledge on the hazards, the severity of consequences or the risks due to the defeating of safeguards.	4	2.381
I8.	The risk of tampering is underestimated by operators (Lüken et al., 2006)/ Ignorance or underestimation of risk of manipulation-11.4% (Zimmermann, 2007)/ Underestimating the hazards of manipulation (Apfeld et al., 2006)/ The risks of bypassing were underestimated (Chinniah, 2009)	The risk of bypassing is underestimated or overlooked.	4	2.381

Table 4.5 Summary of the incentives for bypassing guards and protective devices in the reviewed articles (continued)

Code	Incentives for bypassing	Unique statement (answering why)	N	%
I9.	Operator did not know that the safety device should be used (Backström & Döös, 2000)/ Did not know-6.7% (Zimmermann, 2007)	Operators do not know that using a safeguard is required.	2	1.190
I10.	Operator forgot to use the safety device (Backström & Döös, 2000)	Operators forget to use the safeguard.	1	0.595
I11.	Operator thought s/he used the safety device (Backström & Döös, 2000)	Operators think that they used the safeguard.	1	0.595
I12.	Operator "acted like others with more experience usually do" (Backström & Döös, 2000)	Operators behave as though they are experienced.	1	0.595
I13.	Person could not express her/his reason of not using the safety device (Backström & Döös, 2000)	Operators cannot explain why they do not use a safeguard.	1	0.595
I14.	Safeguard caused challenges in doing the work and production (Backström & Döös, 2000) / Protective devices hamper production (IFA, 2011)/ Safety systems obstruct the process (Schuster, 2012)/Safeguards hindered performing the working process (Apfeld et al., 2006)/ Workers are not able to efficiently accommodate their work (Freedman, 2004)/ Protective devices hamper the working process (Chinniah, 2009)	Safeguards disturb work process and production.	6	3.571
I15.	Lack of observability (Backström & Döös, 2000)/ "Lack of visibility" (Chinniah, 2015a, 2015b)/ Safeguards hinder the visibility of the production (ISO 12100, 2010)/ Protective devices restricted observation of the working process (Lüken et al., 2006)/ Poor visibility of the working process (KANbrief, 2003)/ For "better visibility" (IFA, 2011)/ Guards hamper the observation of operating process (Neudörfer, 2012)/ Protective devices limit the visibility of the working process or the tools (Apfeld et al., 2006)/ limited observability to see job during activities such as setting (Hopkinson & Lekka, 2013)/ Poor view all around when the guards are in place (Adams, 2001)	Safeguard reduces the visibility of the tools and activities such as working process, production, setting and so forth.	11	6.548
I16.	"Poor reliability" and failure of safety devices cause their manipulation (ISO 12100, 2010)/ Failures cause removing of guards repeatedly or "tripping of interlocks" (Neudörfer, 2012)/ Failures of protective devices interrupted production frequently	Poor reliability of safeguards and their failures (e.g. false alarms, trips, and restarts) disturb the	7	4.167

Table 4.5 Summary of the incentives for bypassing guards and protective devices in the reviewed articles (continued)

Code	Incentives for bypassing	Unique statement (answering why)	N	%
	(KANbrief, 2003)/ Safeguards released false alarms that bothered persons in the work area (Backström & Döös, 2000)/ The emergency stop or interlocks often have random faults (Adams, 2001)/ To avoid interruptions (IFA, 2011)/ Safeguard caused "troublesome restarts" (extracted from the handbooks by (Backström & Döös, 2000))	people and operations in the work area and stimulate a tendency to bypass.		
I17.	Defeating safeguard is easy (Backström & Döös, 2000)/ Switches may be easy to remove (KANbrief, 2003)/ Bypassing the guards is possible with a little effort (Neudörfer, 2012)/ Defeating is accomplished easily (Lüken et al., 2006)/ Tampering was possible without difficulty (Apfeld et al., 2006)/ Defeating or removing safeguards was fast and simple to be carried out especially with available tools (Hopkinson & Lekka, 2013)	Safeguards can be disabled easily and with a little effort.	5	2.976
I18.	Manufacturers deliver the required tools for bypassing with machines (Apfeld et al., 2006)/ The tools for disabling safeguards were accessible (Hopkinson & Lekka, 2013)	The required tools or keys for defeating are accessible in enterprises.	2	1.190
I19.	Safeguards were disabled for machine adjustment, fault finding, corrective maintenance or repair (Backström & Döös, 2000) / Installation, disturbance clearing, or maintenance require safeguards removal (Mattila et al., 1995)/ For carrying out some special operational modes e.g. maintenance, defeating needed (Lüken et al., 2006)/ No specific modes of operation exist for performing a specific task on the machine (KANbrief, 2003)/ Tasks are possible with defeating (IFA, 2011)/ Safety systems are removed for implementing installation, maintenance, and faultfinding because of their unsuitable design (Charpentier & Sghaier, 2012)/ Maintenance and operation are not performed easily with enabled safety systems (Schuster, 2012)/ Workers need to defeat safeguard for removing jams (Adams, 2001)/ The operators were able to carry out the installation more quickly with defeating (Apfeld et al., 2006)/ Operators tend to bypass safeguards for troubleshooting (Freedman, 2004)/ Safegurads need	Safeguard removal is necessary to perform activities such as adjustment, troubleshooting, maintenance, and installation.	13	7.738

Table 4.5 Summary of the incentives for bypassing guards and protective devices in the reviewed articles (continued)

Code	Incentives for bypassing	Unique statement (answering why)	N	%
	to be defeated to perform jobs (Roudebush, 2005)/ Overriding is acceptable to carry out setting and maintenance activities, in addition, performing the job such as troublshooting and maintenance is impossible unless by defeating interlocks (Hopkinson & Lekka, 2013)/ Guards are bypassed for machine repair (Chinniah, 2015a, 2015b)			
I20.	Tackling the trips more efficiently with bypassing of protective devices (Apfeld et al., 2006)/ Safety devices were manipulated because the operators "deal with faults more efficiently" (Hopkinson & Lekka, 2013)	Coping with faults would be more efficient with safeguard circumvention.	2	1.190
I21.	Installing and removing guards for lubrication are annoying (Chinniah, 2015a, 2015b)/ Removing and restoring the guard each time for machine lubrication is tedious (Adams, 2001)	Removing and installing safeguards frequently for lubrication is tedious.	3	1.786
I22.	Providing a rapid response to remove fallen products without production interruption (Chinniah, 2015a, 2015b)	Acting quickly to remove products that fell off without interrupting the production.	2	1.190
I23.	"Greater use e.g. for larger workpieces" (IFA, 2011)/ Interlocks needed to be defeated to produce unusual workpieces (e.g. too big or too long) (Hopkinson & Lekka, 2013)	Producing unusual workpieces requires a safeguard defeat.	2	1.190
I24.	Difficulty in performing the job using guards (Gardner et al., 1999)/ Working is "easier or more convenient" (IFA, 2011)/ Convenience-13.4% (Zimmermann, 2007)/ To make the work smoother and more convenient (Apfeld et al., 2006)/ Guards hamper operators from accomplishing their task or cause difficulties in operating machinery and carrying out the work is easier when interlocks were defeated (Hopkinson & Lekka, 2013)	Bypassing provides convenience and facilitates work.	5	2.976
I25.	A safety device "slows down production or interferes with another activity or preference of the operator" (ISO 12100, 2010)/ Protective devices slow down the working process (Lüken et al., 2006)/Slowing down the working process (Apfeld et al., 2006)/ The "machining process" slows down when interlocks were enabled (Hopkinson & Lekka,	Safeguards in place slow down the work process and production.	4	2.381

Table 4.5 Summary of the incentives for bypassing guards and protective devices in the reviewed articles (continued)

Code	Incentives for bypassing	Unique statement (answering why)	N	%
	2013)			
I26.	Safety devices are not easy to use (ISO 12100, 2010)/ Operating guards is not easy (Neudörfer, 2012)/ Safety systems are difficult to use (“cumbersome or impractical”) (Schuster, 2012)/ Inadequate and impractical guards make the ability to do the activity or access to the machine difficult (Hopkinson & Lekka, 2013)	Safeguards are difficult to use because they are impractical.	4	2.381
I27.	“Persons other than the operator are involved” (ISO 12100, 2010)	Other individuals are involved, not just operators.	1	0.595
I28.	The safety device is unsuitable and it is not acceptable for operators (ISO 12100, 2010)/ Improper protective devices have been selected in its design (IFA, 2011)	Unsuitable safeguard has been selected at the design phase, which is unacceptable to the operator.	2	1.190
I29.	There are no limitations to accessing software associated with safety (ISO 12100, 2010)/ Accessing switches may be easy (KANbrief, 2003)	Easy access to software and switches make safeguard is possible to defeat.	2	1.190
I30.	The safety devices are not maintained correctly to attain “the required level of protection” (ISO 12100, 2010)	Safeguards are not maintained correctly to ensure complete protection.	1	0.595
I31.	Guards on machinery cause insufficient “ambient lighting” (ISO 12100, 2010)/ Inadequate light to see inside the machine (Hopkinson & Lekka, 2013)	Safeguard limits the adequate lighting in a workplace.	2	1.190
I32.	To diminish downtime due to production disturbances (Chinniah & Bourbonniere, 2006)	Bypassing increases downtime due to production disturbances.	1	0.595
I33.	To increase “pace of work” (Lüken et al., 2006)/ To work “faster or with greater productivity” (IFA, 2011) / Increasing productivity because protective devices reduce productivity (Apfeld et al., 2006)/ To preserve “production pace” at a steady state (Freedman, 2004)/ Productivity pressures, production demands and carrying out the work more quickly (Hopkinson & Lekka, 2013)/ Production requirements and achieving the production goals at any cost (Johnson, 1999)	Safeguard is an obstruction in quickening the pace of work and enhancing productivity.	6	3.571

Table 4.5 Summary of the incentives for bypassing guards and protective devices in the reviewed articles (continued)

Code	Incentives for bypassing	Unique statement (answering why)	N	%
I34.	Man-machine interfaces are not user-friendly and are not suitable ergonomically (Lüken et al., 2006)/ Poor ergonomics-15.4% (Zimmermann, 2007)/ Poor ergonomics of machinery (Huelke et al., 2006)/ Inadequate ergonomics of safety devices or machinery (Apfeld et al., 2006)/ "Poor worker-machine interface" and protective devices were not user-friendly (Hopkinson & Lekka, 2013)	Machinery and safeguards are not user-friendly and have poor ergonomics.	5	2.976
I35.	Lack of workspace when using safety devices (Lüken et al., 2006)	There is not enough workspace when using a safeguard.	1	0.595
I36.	Workshops tolerate defeating (KANbrief, 2003)/ Manipulation has been tolerated or ordered-6% (Zimmermann, 2007)/ Managers may encourage operators to disable guards (McConnell, 2004)/ Enterprises tolerate defeating (Apfeld et al., 2006)/ Management "turns a blind eye", neglecting or stimulating the tampering of interlocks (Hopkinson & Lekka, 2013)/ Management was proud of workers who tampered, which created production growth (Sherrard, 2007)	There is a lack of management commitment and managers ordered, tolerated, encouraged or ignored circumvention.	6	3.571
I37.	"Negative consequences for the manipulator" are ignored (Lüken et al., 2006)/ Lack of organizational enforcement and disciplinary actions (there were no negative consequences for those who defeated safeguards) (Hopkinson & Lekka, 2013)/ Lack of disciplinary action for bypassing protective devices (Chinniah, 2009)/ Negative consequences were neglected to be carried out for employees who defeated protective devices (Apfeld et al., 2006)	There is no enforcement or disciplinary actions for those who bypass safeguards.	4	2.381
I38.	For "greater precision" (IFA, 2011)	Safeguard is bypassed to obtain greater precision.	1	0.595
I39.	For "better audibility" (IFA, 2011)	Safeguard is bypassed to have better audibility.	1	0.595
I40.	To require "less physical effort" (IFA, 2011)	Safeguard is bypassed to require less physical effort.	1	0.595
I41.	To decrease the rate of travel (IFA, 2011)	Safeguard is bypassed to reduce the rate of	1	0.595

Table 4.5 Summary of the incentives for bypassing guards and protective devices in the reviewed articles (continued)

Code	Incentives for bypassing	Unique statement (answering why)	N	%
		travel.		
I42.	To have "greater freedom of movement" (IFA, 2011)/ Facilitate movement (Apfeld et al., 2006)	Safeguard is bypassed to facilitate movement.	2	1.190
I43.	To improve "flow of movements" (IFA, 2011)	Safeguard is bypassed to improve the flow of movement.	1	0.595
I44.	Time saving-22.8% (Zimmermann, 2007)/ To save time (Apfeld et al., 2006)/ To gain time because accomplishing the job takes a longer time when using interlocks (Hopkinson & Lekka, 2013)/ The time of operation will be shortened (Adams, 2001)	Safeguards are bypassed to save time in carrying out the operations.	4	2.381
I45.	Unsuitable machine-15.4% (Zimmermann, 2007)	There is an unsuitable machine to work with.	1	0.595
I46.	Habit-8.7% (Zimmermann, 2007)	Bypassing is a habit.	1	0.595
I47.	Stress (Zimmermann, 2007)/ "Stress, feeling of panic or competitiveness" (Johnson, 1999)	Safeguard is bypassed because of stress.	2	1.190
I48.	Guards "vibrate or rattle". (Neudörfer, 2012)	Safeguard vibrates or rattles.	1	0.595
I49.	Experienced operators perceived that they are less at risk than novices when they defeated interlocks; therefore, the probability of defeating by experienced operators is higher than others (Hopkinson & Lekka, 2013)	Bypassing occurs with experienced operators because they think that they are less at risk than others.	1	0.595
I50.	Being under pressure because of time (Apfeld et al., 2006)/ Time pressures to meet customer needs and also time is tight to reinstate removed guards (Hopkinson & Lekka, 2013)	There is time pressure to perform the job or to meet expectations.	2	1.190
I51.	Absence of awareness and training related to protective device manipulation (Apfeld et al., 2006)/ Inappropriate skills or training on machine or processes (Hopkinson & Lekka, 2013)/ "Ignorance" and training workers insufficiently (Johnson, 1999)	There is a lack of adequate training and awareness about manipulation.	3	1.786
I52.	Supervisors or managers did not recognize that protective devices had been defeated (especially sometimes the defeated safety devices are restored and their tampering is not identifiable) (Apfeld et al., 2006)/ Defeating interlocks especially on older machines is not easily detected (Hopkinson & Lekka, 2013)	Bypassing a safeguard is not detectable because they are usually restored or bosses are not able to detect it.	2	1.190
I53.	Employees were not involved in buying new	Employee involvement	2	1.190

Table 4.5 Summary of the incentives for bypassing guards and protective devices in the reviewed articles (continued)

Code	Incentives for bypassing	Unique statement (answering why)	N	%
	machinery (Apfeld et al., 2006)/ Lack of employee participation in OHS issues (Hopkinson & Lekka, 2013)	is ignored for procuring machine or other OHS issues.		
I54.	Operators are forced to bypass protective devices by experienced workers or do this behavior with another colleague (Apfeld et al., 2006)	Experienced operators force others to bypass or defeating is carried out with peers.	1	0.595
I55.	"Poor machine design" (Hopkinson & Lekka, 2013)	Machine design is poor.	1	0.595
I56.	Lack of flexibility in CNC machines such that the program goes back to the beginning when the machine is stopped for swarf removal and etc., and it cannot be restarted "mid-program" or whether the guards had to be enabled all the time or just during CNC mode (Hopkinson & Lekka, 2013)	There is a lack of flexibility in programming (e.g. a program that goes back to the beginning when the machine was stopped for swarf removal, etc., and it cannot be restarted mid-cycle or when the safeguard has to be enabled all the time or just during CNC mode.)	1	0.595
I57.	The regulatory requirements do not clarify whether guards should be operated all the time or just during operations in CNC mode (Hopkinson & Lekka, 2013)	The regulatory requirements do not clarify whether safeguards should be operated all time or just when operating in CNC mode.	1	0.595
I58.	Impaired accessibility to the job (e.g. cleaning) and the tools (Hopkinson & Lekka, 2013)	There is impaired accessibility to the job and the tools.	1	0.595
I59.	To gain "performance bonuses" in organizations; thus, operators try to implement their tasks correctly even with defeating interlocks (Hopkinson & Lekka, 2013)/ To gain positive reaction or encouragement from supervisors or bosses following increased productivity (Adams, 2001)	Bypassing occurs to obtain encouragement and performance bonuses from bosses.	2	1.190
I60.	Operators disabled protective devices when there was no supervision (Hopkinson & Lekka, 2013)	There is no supervision with monitoring that a safeguard is enabled.	1	0.595
I61.	"Financial pressures" (Hopkinson & Lekka, 2013)	Bypassing occurs	1	0.595

Table 4.5 Summary of the incentives for bypassing guards and protective devices in the reviewed articles (continued)

Code	Incentives for bypassing	Unique statement (answering why)	N	%
		because of financial pressures.		
I62.	The interlocks were not checked before operating the machine (Hopkinson & Lekka, 2013)	Safeguards are not checked before operating the machine to ensure that they are in place.	1	0.595
I63.	The defeating problem is not integrated into a culture of safety (Hopkinson & Lekka, 2013)	The defeating issue is not integrated into a culture of safety.	1	0.595
I64.	Existing inappropriate policies and procedures (Hopkinson & Lekka, 2013)	Current policies and procedures are inadequate.	1	0.595
I65.	Time costs due to the program restarting are reduced (Hopkinson & Lekka, 2013)	The time costs due to a program restart are reduced.	1	0.595
I66.	Manufacturers installed inappropriate and impractical guards with poor quality machinery (Hopkinson & Lekka, 2013)	Machines are produced with safeguards of poor quality by manufacturers.	1	0.595
I67.	Not meeting the due date of a customer order decreased profitability (Hopkinson & Lekka, 2013)	Profitability diminishes if the customer's order is not met.	1	0.595
I68.	Safeguards are too heavy to move, and removing or replacing them is tough (Adams, 2001)	Moving the heavy safeguard is difficult.	1	0.595
I69.	The guard is huge and makes it difficult to access around or over it (Adams, 2001)	The safeguard's size makes it difficult to access areas around it.	1	0.595
I70.	The "sharp edges" or "protruding" screws of guards trap clothes or cause cuts (Adams, 2001)	Clothing is caught or cuts happened because of the physical characteristics of a safeguard.	1	0.595
I71.	"Metabolic energy" consumption will decrease (Adams, 2001)	Metabolic energy consumption will decrease by bypassing.	1	0.595
I72.	Employees are intrinsically excited to take risk (Adams, 2001)	Taking a risk is exciting for employees.	1	0.595
TOTAL			168	100

4.6 Proposals for preventing bypassing of guards and protective devices

Lüken et al. (2006) explained that German research on bypassing protective devices on machinery (Apfeld et al., 2006) has discussed solutions to resolve the defeating of protective devices in terms of technical, organizational, ergonomic, and psychological standpoints. Thus, they recommended a systematic procedure to prevent bypassing on an individual, organizational, and technical level. IFA (2011) has considered corrective measures in three phases, including the designing, purchase, and operation of machinery. Additionally, the study suggested that if the above-mentioned measures are impossible to implement, organizational measures need to be sought because it should be clarified that the manipulation of protective devices will not be tolerated in enterprises. Apfeld (2010) stated that a website (Stop-defeating) has been launched to share general information for manufacturers, suppliers, and users to prevent defeating of safeguards on machinery. Suva started a campaign to address employers and promote their knowledge regarding the problems and risks involved in manipulation, leading to a significant reduction in the number of circumventions and also to reinforce controls (Zimmermann, 2007). Hopkinson and Lekka (2013) revealed possible factors for improvement in behavior in organizations to prevent defeating. Adams (2001) perceived that the application of human factors in design techniques decreases the benefits of disabling safeguarding systems.

Table 4.6 provides suggestions and recommendations regarding the prevention of bypassing provided by several references. Similarly to the incentives, the solutions are listed with possible redundancies in the findings due to the lack of detail in some reviewed references. The references have discussed influential factors that are constituted by combination of their experience or their experiential evidence. Similar suggestions are classified in one group. Solutions are coded starting with S (first letter of Solution) in this table, and these items are not necessarily related to the corresponding number in Table 4.5.

Table 4.6 Proposals to mitigate bypassing of safeguards and protective devices

Code	Solutions to prevent bypassing
S1.	Checking two tasks should be considered in the strategies of preventive maintenance including the following: (i) the defeated safeguards were reinstated to the former place, (ii) existing safeguards were in operative condition (Chinniah, 2015a).
S2.	Taking into account special control mode in design that deactivates all other control modes concurrently when a safeguard has to be bypassed. The operation will be carried out in that control mode only by using an enabling device, a hold-to-run device or a two-hand control device or at reduced speed (Chinniah, 2015a).

Table 4.6 Proposals to mitigate bypassing of safeguards and protective devices (continued)

Code	Solutions to prevent bypassing
S3.	Connecting safeguards to the control system such that the machine will be halted when the guards are removed (Mattila et al., 1995).
S4.	Clarifying procedures that put the existing guards in place (Mattila et al., 1995)./ Designing working processes with regards to the utilization of protective devices (Apfeld et al., 2006).
S5.	Considering all life cycle and operating modes of machinery during machine building (Lüken et al., 2006).
S6.	Using engineering methods such as "intelligent camera systems" to avoid operators suffering ergonomically and from economic loss (Lüken et al., 2006).
S7.	Developing a "systematic procedure" to stop defeating with regards to the technical, organizational, and individual levels (Lüken et al., 2006).
S8.	Cooperating closely between safety device building engineers, electrical engineers, and suppliers is required in the construction stage and integrating protective measures and machines in that stage (Lüken et al., 2006).
S9.	Boosting interfaces between man and machine and accepting the safety devices (Lüken et al., 2006)./ Considering a user's convenience and ergonomic concepts at the design phase for operating and protecting machinery (KANbrief, 2003). / Promoting the interfaces between individuals and machines to facilitate the working process with protective devices (Apfeld et al., 2006).
S10.	Procurement of a machine should be made on the basis of an employee's point of view and checklists (Lüken et al., 2006)./ Involving workers should be improved during the process of purchasing a machine, selecting a machine and they should also be involved in safety improvements (Hopkinson & Lekka, 2013)./ Collaboration between OHS experts, production and maintenance professionals (individual involvement) to plan and to purchase new machines (Apfeld et al., 2006).
S11.	Taking into account the related standards by designers to stop manipulation or make it difficult (KANbrief, 2003).
S12.	Reviewing and improving type-C[14] standards to consider technical measures to avoid defeating and practical actions to apply their concepts to operating and protecting equipment (KANbrief, 2003).
S13.	Making a link between manufacturers and workers by OHS organizations (KANbrief, 2003).
S14.	Designing better protective systems (Järvinen & Karwowski, 1993)./ Improving safeguard and machine design (e.g. to have better visibility) (Apfeld et al., 2006)./ Skilled designers should design safety systems by considering the achievement of required productivity and safety at a workplace simultaneously (Freedman, 2004)./ Improving safeguard characteristics in design will reduce motives for manipulation, for instance, "using mirrored surfaces" for better visibility, providing sufficient lighting, improving "viewing angles", and replacing them more easily (Adams, 2001).
S15.	Improving ergonomic designs that are undesirable (e.g. for frequent intervals, a light curtain

[14] type-C standards (machine safety standards) deal with "detailed safety requirements for a particular machine or group of machines." (ISO12100, 2010)

Table 4.6 Proposals to mitigate bypassing of safeguards and protective devices (continued)

Code	Solutions to prevent bypassing
	may be more satisfactory than a protective gate) (IFA, 2011).
S16.	Providing the required operating modes, applying “drive controls” with reduced speed when operating a machine while performing tasks is not possible without tampering (IFA, 2011)./ Defining and installing a new operational mode to facilitate the faultfinding process and then solving it (Apfeld et al., 2006).
S17.	Evaluating the incentive of defeating before purchasing any machine by consulting with future users (IFA, 2011).
S18.	Considering possible design solutions or modifications to remove the incentives of defeating during the operation of existing machinery. (IFA, 2011)
S19.	An assessment matrix in an Excel spreadsheet (including tasks, modes of operation, benefits of bypassing protective device) was suggested to assess the incentives to bypass (IFA, 2011). In 2016, the IFA developed this matrix as an application for Android and IOS (Stop-defeating).
S20.	A brief checklist has been proposed to stop the manipulation of protective devices, to prevent and to control dangers due to tampering. The checklist consists of four parts: (i) purchasing a new machine, (ii) normal running, (iii) particular running, maintenance, (iv) organization, training, and human behavior. Furthermore, the checklist will be applied to determine the defeated protective devices and their reasons (Suvapro, 2007).
S21.	Considering all possible ways for bypassing during a risk assessment such as “crawling below the lowest beam”, “reaching over the top beam” or “passing between two beams”. In addition, the height and minimum distance should be calculated to prevent bypassing electro-sensitive protective equipment. If necessary, additional safeguards shall be provided to prevent circumventing (ISO 13855, 2010).
S22.	A checklist for machine purchase has been prepared to examine the intentions of defeating during the procurement process (DGUV, 2013).
S23.	Improving work process and adherence of internal safety rules systematically (Zimmermann, 2007).
S24.	Employer liability: they are responsible and they have a key role in respecting OHS rules, ensuring the effectiveness of protective devices; tolerating or ordering the manipulation of them should be punishable, accidents due to bypassing and even existing defeated devices can cause legal troubles for them (Zimmermann, 2007).
S25.	Workers’ responsibilities: They are strictly forbidden to modify or remove the safety devices (Zimmermann, 2007)./ An operators’ responsibility should not be lightened (KANbrief, 2003).
S26.	Strengthening of controls by focusing on the manipulation of safety devices in the controls and applying a practical tool proposed by (Suvapro, 2007) to identify the bypassed devices and their reasons (Zimmermann, 2007).
S27.	The functionality of safety measures and the aim of using them should be assessed as an element of a work system design with regards to relevant standards to prevent bypassing (Peter, Lungfiel, Nischalke-Fehn, & Trabold, 2013).
S28.	Guards and protective devices can be protected against bypassing with new technological advances, significant expenditures for controls, and by considering “safety engineering aspects” (Neudörfer, 2012).
S29.	Applying passive design, which can be activated without needing the operator to do anything, or configurable design, which authorizes a worker to change the manner of safety system based on the job to be accomplished; this would diminish the incentive to bypass (Schuster,

Table 4.6 Proposals to mitigate bypassing of safeguards and protective devices (continued)

Code	Solutions to prevent bypassing
	2012)./ Utilizing presence sensing systems, interlocks systems as passive protective devices would decrease the probability of bypassing because the cost of their manipulation is high, and two-hand control will promote visibility (Adams, 2001).
S30.	Providing appropriate supervision has an influence on avoiding the overriding of safety systems (Dźwiarek, 2004)./ Sufficient monitoring by line management and safety professionals ensures that safeguards are in place or that they define corrective measures for non-compliance (McConnell, 2004)./ Monitoring violations and persistently enforcing them (Apfeld et al., 2006).
S31.	Individuals are responsible for using safeguards correctly (McConnell, 2004)./ Employees should perceive their responsibility for safeguarding and all relevant programs (Johnson, 1999).
S32.	A “Machine safeguarding program” should be documented to ensure suitable safeguards are provided and used (McConnell, 2004).
S33.	Individuals should raise their awareness (Hopkinson & Lekka, 2013).
S34.	Providing training for employees to perceive the necessity of using the safety devices ((Department of Health State of New York, 2004) cited in (Hopkinson & Lekka, 2013))./ Training and raising the operators’ competence to operate CNC machines (Hopkinson & Lekka, 2013)./ Training can prevent defeating by increasing the knowledge of the hazards related to defeating and its “legal consequences” (Apfeld et al., 2006)./ Training of employees should not be overlooked. Their knowledge should be promoted by teaching the basic concepts of machine guarding; teaching should be compatible with existing, precise policies (Sherrard, 2007)./ Appropriate training has an influence on avoiding the overriding of safety systems (Dźwiarek, 2004)./ Training individuals is essential to prevent bypassing (Freedman, 2004).
S35.	Clarifying that overriding is not tolerated by management and notifying operators of the legal and negative consequences (Apfeld et al., 2006)./ Showing management commitment by talking with individuals, paying attention to recommendations and “following up with positive feedback” (Johnson, 1999).
S36.	Performing discipline (Apfeld et al., 2006)./ Establishing “evaluation, reward and disciplinary systems” and related records should be documented (Hopkinson & Lekka, 2013).
S37.	Promoting managers’ awareness of hazards and improving management commitment (Hopkinson & Lekka, 2013).
S38.	Developing a health and safety culture at all organizational levels (e.g. operators, supervisors, managers) (Apfeld et al., 2006).
S39.	Developing and implementing safety management systems including machine safety programs, defining policies, procedures for safe operating, emergency situations, removing jams or maintenance, training plans, fault reporting systems, and considering all tasks and operation modes at risk assessment ((New York State Department of Health, 2004) cited in (Hopkinson & Lekka, 2013))./ Developing a concise document such as OHSAS18001 as a best practice or implementing an effective safety management system to prevent overriding of interlocks (Hopkinson & Lekka, 2013).
S40.	Engaging OHS committees to facilitate and follow improvements (D. L. Parker et al., 2009).
S41.	Providing new machines or upgrading existing machines (Apfeld et al., 2006).
S42.	Assigning a required time for retraining operators (Apfeld et al., 2006)./ Employers should retrain employees (Johnson, 1999).

Table 4.6 Proposals to mitigate bypassing of safeguards and protective devices (continued)

Code	Solutions to prevent bypassing
S43.	Manufacturers and enterprises should communicate with each other to find technical solutions to make operations quicker and more convenient with no need for manipulation of protective devices (Apfeld et al., 2006).
S44.	Manufacturers should be familiar with the legal consequences due to tampering (Apfeld et al., 2006).
S45.	Considering appropriate protective devices during a machine building phase to construct a user-friendly machine (Apfeld et al., 2006).
S46.	The main criteria to select the protective devices in a machine manufacturing phase should be its sufficiency, not its cost (Apfeld et al., 2006).
S47.	Implementing a “visual and functional check” before starting up production (Apfeld et al., 2006).
S48.	Enterprises should evaluate the defeat cases and possible improvements in a top-down approach (Apfeld et al., 2006).
S49.	Using technical solutions such as “storage of programmable controls (SPC)” so the operation will be stopped or interrupted if bypassing occurs, and using “concealed mounted switches with coded mating components and tamper-proof fastening of protective devices” that make manipulation difficult (Apfeld et al., 2006).
S50.	Carrying out a risk assessment by considering all operating modes, tasks, and all the manufacturing phases of a machine is the most efficient way to prevent defeating (Apfeld et al., 2006)./ Accomplishing a risk assessment within the design phase and before commissioning to ensure that in the integrated process (considering productivity and safety together), there are no new hazards (Freedman, 2004).
S51.	Individuals should ensure that safeguards are reinstated before operating the equipment by using “administrative measures such as hazard warning signage, safe working procedures, and employee training” (Roudebush, 2005).
S52.	Developing an inspection checklist and performing it at certain intervals to ensure that the protective devices are used and its records should be maintained ((New York State Department of Health, 2004) cited in (Hopkinson & Lekka, 2013))./ Performing periodical checks by managers and supervisors to ensure that interlocks were activated (Hopkinson & Lekka, 2013)./ Conducting an annual audit and also conduct the audits during different shifts to ensure that guards are not disabled; records should be maintained (Johnson, 1999)./ Inspecting machines in an independent process by individuals outside of that department, such as external consultants, because the hazards are ignored if a workplace is evaluated by its own workers (Sherrard, 2007).
S53.	Conducting “program stop” and “automatic probing systems” that will facilitate setting activities, such that the defeat of interlocks will not be necessary (Hopkinson & Lekka, 2013).
S54.	Engaging supervisors as OHS promoters (Hopkinson & Lekka, 2013).
S55.	Considering defeating when defining the plans and goals of organizations (Hopkinson & Lekka, 2013).
S56.	Workers perceive that they are supported in the promotion of safety issues if managers provide an “open culture” (Hopkinson & Lekka, 2013).
S57.	Designers and manufacturers should figure out methods together to decrease the motives of defeating interlocks (Hopkinson & Lekka, 2013).
S58.	Manufacturers should highlight the purpose of safety devices and train organizations on how to

Table 4.6 Proposals to mitigate bypassing of safeguards and protective devices (continued)

Code	Solutions to prevent bypassing
	operate the machine with enabled safety devices for a new machine purchase (Hopkinson & Lekka, 2013).
S59.	Installing “video cameras” on CNC machines or the use of “better quality glass” will help operators monitor their working process (Hopkinson & Lekka, 2013).
S60.	Manufacturers should install guards with better quality, “more damage-resistant” without causing obstruction to view the working process (Hopkinson & Lekka, 2013).
S61.	Manufacturers should develop better programming so that operators can resume a task when the machine is interrupted (Hopkinson & Lekka, 2013).
S62.	Applying “error messages”, “audible or visible alarms” on machines to detect the defeated interlock or safety gates opened and to warn operators (Hopkinson & Lekka, 2013).
S63.	Accessing tools and keys that would be applied to defeat interlocks should be restricted (Hopkinson & Lekka, 2013).
S64.	Adequate supervision of naïve operators (Hopkinson & Lekka, 2013).
S65.	Evaluating the effectiveness and following feedback from communication campaigns, safety signage, explicit images, and videos at toolbox talks to promote awareness (Hopkinson & Lekka, 2013).
S66.	Considering strategies that do not approve this behavior to change managers’, supervisors’, and operators’ attitudes such as communication campaigns, toolbox talks, and retraining at regular intervals. (Hopkinson & Lekka, 2013)
S67.	Considering explicit guidance that will change an operator’s beliefs and will promote the use of safety devices (Hopkinson & Lekka, 2013).
S68.	Considering the maintenance schedule suggested by manufacturers ((New York State Department of Health, 2004) cited in (Hopkinson & Lekka, 2013)).
S69.	Manufacturers should render clear guidelines for the operation and maintenance of safety devices for employers ((New York State Department of Health, 2004) cited in (Hopkinson & Lekka, 2013)).
S70.	Supervisors are responsible for establishing “positive changes” or changes of personnel to show others that safety is the priority (Johnson, 1999).
S71.	Facilitating a guard’s removal, but connecting it to machinery with a safe fastening (Adams, 2001).
S72.	Installing an emergency stop button within height and out of reach to prevent accidental trips (Adams, 2001).
S73.	The guards should be visible, for example, with salient colors to attract individuals’ attention (Adams, 2001).
S74.	Paying attention to housekeeping, for example by installing trays where debris accumulates behind guards (Adams, 2001).
S75.	Situating handles by considering the postures of shoulders and wrists simplifies the removal of guards and then reinstalling them (Adams, 2001).
S76.	Guards with one contact point facilitates replacement (Adams, 2001).
S77.	If the guards are multifunctional, for example as guides for inserting a part, the worker will understand the importance of them (Adams, 2001).
S78.	Heavy guards need supports to facilitate mounting (Adams, 2001).
S79.	Guards that are large in size should be attached with hinges to avoid the need to lift them, and also guards that are heavy in weight prevent manual removal (Adams, 2001).

Table 4.6 Proposals to mitigate bypassing of safeguards and protective devices (continued)

Code	Solutions to prevent bypassing
S80.	(i) Manufacturers can facilitate the use of safety devices constantly, (ii) manufacturers can improve the convenience of existing safety devices, and (iii) manufacturers develop new concepts to minimize the required workers’ effort, (iv) manufacturers can develop additional safety devices for old machines (Pratt & Hard, 1998).
S81.	Preventive measures in design have been used to reduce the motives of defeating interlocking devices (ISO 14119, 2013).
S82.	Designers are required (i) to limit safety functions and programming through locks or passwords, (ii) to connect protective devices to the control system, (iii) to define a specific control mode for setting, teaching, process changeover, faultfinding, cleaning or the maintenance of machines, (iv) to render guards and protective devices compatible with the working environment, (v) to provide minimum interference with other activities, (vi) to cause minimum obstruction to view the production process so that guards and protective devices cannot be easily defeated or do not need to be removed or disabled during installation, replacement of tools and maintenance, (vii) to tighten fixed guards in place by fasteners (screws, nuts) (ISO 12100, 2010).

Designers, manufacturers and users of machines should be motivated and supported to prevent the practice of defeating guards and protective devices. As KANbrief (2003) noted, machine designers, machinery manufacturers and operators are all responsible for reducing the frequency of these kinds of manipulations. This summary also stated that technical solutions are available in ISO 14119 to refer to during the design stage.

According to the information extracted that was related to the solutions in Table 4.6, most solutions are recommendations to prevent bypassing guards and protective devices and only three tools are suggested, including an assessment matrix (IFA, 2011), a checklist to use when purchasing machinery (DGUV, 2013), and a checklist to stop the manipulation of protective devices (Suvapro, 2007). As we can see in Table 4.6, some solutions are related to the design phase, some to the manufacturers of machinery and some that are related to the end users. International standards provide technical solutions for the prevention of defeating during the design phase, which is arguably the most efficient time to implement these solutions. Collier (2014) introduced “defeating of interlocking devices” as one of the technical differences between EN1088 and ISO 14119 standards. Thus, Section 7 of (ISO 14119, 2013) describes measures to prevent defeating, such as making interlocking devices inaccessible. Moreover, designers are responsible for minimizing the incentives for bypassing safeguards by having a thorough understanding of how their machines will be used at each stage of their lifecycle. In addition, Section 8 of (ISO 13851, 2002) describes considerations to help avoid tampering on two-hand control devices. The requirements to prevent the circumvention of electro-sensitive protective equipment are determined in Section 6.5 of (ISO 13855, 2010).

According to Section 1.2.5 of (Le parlement européen, 2009), some conditions have been determined that ensure a safe intervention zone when machinery must be operated when a guard is displaced or removed, and a protective device that can be disabled for certain operations. Blaise and Welitz (2010) demonstrated an operating mode that is called "Production Protection Devices Neutralized". This mode of operation provides protection during observation operation (including process validation, adjustment, and maintenance). In this operating mode, it should be noted that: (i) any change of mode must be activated by a selector and must therefore include a stop between the two modes even in the observation mode, (ii) wearing PPE against the residual risks, (iii) a control point in an observation zone must be equipped with an operational device that ensures a normal stop for operational reasons or an emergency stop, (iv) authorized personnel are permitted to access observation zones. To stop the overriding of protection, Apfeld (2010) revealed that the bypassing issues are not sufficiently taken into account in the field of OHS.

4.7 Discussion and Analysis

Generally speaking, numerous literature reviews have investigated the subject of regulation conformity as well as that of regulation violation. In their review, Hale and Borys (2013) considered managing safety rules and procedures and identified potential incentivizing factors related to the violation of safety rules. Alper and Karsh (2009) reviewed the experimental reasons in industries related to the safety rule violations. Additionally, HSE published a report showing potential means of identifying procedural violations, as well as suggesting measures for improving these concerns (HFRG, 1995). Safeguard bypassing may be considered a type of rule violation when safety rules emphasize the use of guards and protective devices as stated in Section 4.3.2. Little research exists on the subject of incentives to bypass within work environments, as well as preventive solutions to address these issues, and no review paper directly addressed the topic of the bypassing of guard and protective devices. Furthermore, in this paper, a sufficiently comprehensive picture of bypassing can be gleaned by reviewing the definitions of bypassing, reading a summary of standards and regulations related to bypassing, reviewing published information on accidents, potential incentives to bypass, as well as potential recommendations to prevent bypassing. This comprehensive portrait will provide a sufficient understanding of the problem so as to enable the design of a tool to prevent bypassing, as well as identifying insights that will fulfill the needs of researchers and OHS preventionists for an easy-to-access and comprehensive reference resource that summarizes available bypassing studies.

4.7.1 Incentives to bypass safeguards

The incentives to bypass that have been discussed were extracted from 24 reviewed papers and other types of references. The authors had various views on this behavior, and the incentives to bypass were classified within groups of similar responses, as shown in Table 4.5. These incentives were categorized into 72 unique groups drawn from all of the available studies. The frequency of each unique group and its percentage were calculated; Table 4.7 details the incentives that the majority of authors found in their studies throughout different machines or systems and different countries. Table 4.7 also suggests that there are significant motives for bypassing in all studies. Removing safeguards to perform activities such as adjustment, troubleshooting, maintenance, and installation (7.738%) was the most frequent incentive cited amongst all studies. It was found that (6.548%) of incentives were linked to a lack of visibility, whereas (4.167%) were linked to failures and poor reliability. Production disturbances, the need to work faster and to obtain greater productivity, and lack of management commitment contributed equally (3.571%) as incentives for bypassing in all studies. Being able to disable safeguards easily, additional convenience, as well as poor ergonomics and poor man-machine interface were other contributing incentives to bypass, each with the same percentage (2.976%). The same percentage (2.381%) was attributed across studies stating that

- operators felt that machines were safe without safeguards, had a lack of knowledge on risks, underestimated potential risks, needed to save time.
- safeguards slow down production or are difficult to use,
- organizations had a lack of disciplinary consequences.

The most frequent incentives have been selected based on the Pareto principle (80-20 rule). That principle states that 20% of the causes (here, incentives) of a phenomenon (here, bypassing) explains roughly 80% of that phenomenon. Applying that rule, 20% of the 72 identified incentives is equal to 14.4. Consequently, incentives number 1 to 14 would explain most of the bypassing phenomenon. However, since the fourteenth to the sixteenth incentives have the same percentage, the first 16 most frequent incentives have been considered in Table 4.7.

Table 4.7 The most frequent incentives to bypass by their occurrence in the references

NO.	Incentives for bypassing	N	%
1.	Safeguard removal is necessary to perform activities such as adjustment, troubleshooting, maintenance, and installation (I19).	13	7.738
2.	Safeguard reduces the visibility of the tools and activities such as working process, production, setting and so forth (I15).	11	6.548
3.	Poor reliability of safeguards and their failures (e.g. false alarms, trips, and restarts) disturb people and operations in the work area and stimulate a tendency to bypass (I16).	7	4.167
4.	Safeguards disturb work process and production (I14).	6	3.571
5.	Safeguard is an obstruction in quickening the pace of work and enhancing productivity (I33).	6	3.571
6.	There is a lack of management commitment and managers ordered, tolerated, encouraged or ignored circumvention (I36).	6	3.571
7.	Safeguards can be disabled easily and with a little effort (I17).	5	2.976
8.	Bypassing provides convenience and facilitates work (I24).	5	2.976
9.	Machinery and safeguards are not user-friendly and have poor ergonomics (I34).	5	2.976
10.	Operators feel machines are safe without safeguards, and using them is unnecessary (I6).	4	2.381
11.	There is a lack of knowledge on the hazards, the severity of consequences or the risks due to the defeating of safeguards (I7).	4	2.381
12.	The risk of bypassing is underestimated or overlooked (I8).	4	2.381
13.	Safeguards in place slow down the work process and production (I25).	4	2.381
14.	Safeguards are difficult to use because they are impractical (I26).	4	2.381
15.	There is no enforcement or disciplinary actions for those who bypass safeguards (I37).	4	2.381
16.	Safeguards are bypassed to save time in carrying out the operations (I44).	4	2.381

Apfeld et al. (2006) presented four viewpoints on the incentives for tampering including psychological, ergonomic, organizational and technical. Furthermore, as indicated in Section 4.5, Hopkinson and Lekka (2013) regarded three sets of influencing behavior containing predisposing, enabling and reinforcing factors according to the PRECEDE[15] model in the occurrence of defeating interlocks. Based

[15] PRECEDE is a theoretical approach that goes beyond individual-level variables that influence behavior. Three sets of diagnostic factors including predisposing, enabling, and reinforcing have a direct impact on behavior (Hopkinson & Lekka, 2013).

on Table 4.5, the potential incentives to bypass can be grouped into five categories (displayed in Table 4.8):

- *Ergonomics*: incentives induced by difficulties related to man-machine interactions. In this case, machines, tasks and equipment do not adapt with users' capabilities, limitations and needs (e.g. poor visibility, poor accessibility to the job and the tools, among other factors).
- *Productivity*: incentives caused by the fact that there are obstacles to consuming resources (e.g. time, money, etc.) effectively and efficiently. This hinders the creation of added value (e.g. time pressure, using safeguards is extra work, just to name a few).
- *Behavior*: incentives linked to intentional unsafe acts or in some situations "mistaken circumventions" (Reason, 1994) derived from "cognitive processes" (Reason, 1990) where the mind decides to behave in this way (e.g. a habit, underestimating the risk of bypassing, among others).
- *Machines or safeguarding*: incentives related to the features, characteristics and functions of the machinery and tools applied to perform the job and others (e.g. impractical safeguards, safeguard with poor reliability, to name a few).
- *Corporate climate*: according to existing concepts (Neal, Griffin, & Hart, 2000), incentives related to individual perceptions of the work environment that refer to specific factors including leadership, roles, communication, training to develop knowledge and skills, employee participation and management systems that influence individual motivation and attitudes (e.g. lack of management commitment, lack of worker involvement, to name a few).

Consequently, organizations should pay attention to these categories in order to manage manipulation in workplaces.

A work system is a combination of equipment, work environments, organizational structure and individuals (physical and mental states), all of which have an impact on OHS. That is the reason why we propose the five previous categories of incentives for bypassing in order to develop a comprehensive understanding of bypassing for the purpose of developing a preventive tool in future research. These categories can interact with each other with regards to the occurrence of bypassing in enterprises.

The results in Table 4.8 demonstrate that causes related to the productivity and the machine, or safeguarding categories, have the highest contribution, 23.611%, toward defeat. Moreover, Table 4.8

revealed that the subsequent ranks are devoted to the incentives linked to the ergonomics group (19.444%), with behavior and corporate climate categories indicating the same percentage (16.667%), respectively. This evidence once again proves the reality that the design and manufacturing of suitable machines and safeguarding have significant roles in reducing or eliminating bypassing.

Table 4.8 Distribution of the incentives in the primary categories

Primary categories	**Codes**	**N**	**%**
Ergonomics	I15- I21- I24- I31- I34- I35- I39- I40- I41- I42- I43- I47- I58- I71	14	19.444
Productivity	I1- I2- I3- I4- I14- I19- I20- I22- I25- I32- I33- I38- I44- I50- I61- I65- I67	17	23.611
Behavior	I5- I6- I7- I8- I9- I10- I11- I13- I46- I49- I62- I72	12	16.667
Machine or safeguarding	I16- I17- I18- I23- I26- I28- I29- I30- I45- I48- I55- I56- I57- I66-I68- I69- I70	17	23.611
Corporate Climate	I12- I27- I36- I37- I51- I52- I53- I54- I59- I60- I63- I64	12	16.667
TOTAL		72	100

According to Table 4.7, the most frequent incentives are a combination of the primary categories in Table 4.8. It illustrates that all of the principal categories are significant and they should be considered in order to prevent manipulation. Interestingly, the incentives related to the individuals' behaviors reveal the lowest percentages in Table 4.8. It also demonstrates that authors believe that bypassing is not an operator failure exclusively, as there are more fundamental causes behind defeating. As Sherrard (2007) emphasized, the main issue that causes the manipulation to occur in an organization is management, not blue collar workers. Therefore, we strive to find the origins of the problem in order to apply systematic solutions to prevent the bypassing of guards and protective devices, instead of what Alper and Karsh (2009) state as "blaming workers". As such, Chinniah (2015a) emphasized that preventing the bypassing of safeguards is one of the required actions for companies with limited resources in OHS to reduce fatal and serious accidents involving the moving parts of a machine.

4.7.2 Solutions to prevent bypassing protective devices and guards

Proposals for improvement are extracted from the 26 studies reviewed. The suggestions are related to three phases: design, manufacturing and usage. All of the preventive solutions collected in Table 4.6 were analyzed and categorized according to these three phases. Table 4.9 illustrates the number and percentage of the suggestions that are based on these phases. Thirty-nine of the 82 solutions were for the usage phase, which is when enterprises procure and operate machinery as end users. The design and manufacturing phases contain 36.588% and 15.854% of the improvement actions, respectively. The percentages presented in Table 4.9 do not mean that the usage phase has the most impact on avoiding a bypass. They just show that researchers have reported on more varieties of preventive measures (e.g. training, auditing, supervision, employee participation, etc.) for the usage phase than for the other phases, because the actions in the usage phase encompass the work environment and organizational hierarchy. In contrast, in the two other phases, designers and manufacturers focus on machine and safeguarding modifications to promote the use of guards and protective devices. According to the hierarchy established by Figure 4.1, the preventive measures in the design and manufacturing phases are the most efficient ways to remove or eliminate the incentives to bypass guards and protective devices.

Challenges are encountered at each stage. There is a gap between the knowledge and intentions of the designer and the needs and goals of the user; in addition, designers cannot predict all work conditions, which are different in various enterprises. Moreover, ISO 12100 (2010) stated that “even well-designed safeguarding can fail or be defeated”. Furthermore, total protection of a two-hand control from defeating is impossible (ISO 13851, 2002). Manufacturers ignore the rules or the quality of safety devices due to economic reasons. However, companies have to import machinery; thus, they do not have the opportunity to have discussions about equipment during the design and machine building phases or when first commissioning a device. Finally, in organizations that are end users, operators sometimes have to work with old machines that have a poor design that has not adhered to standards and regulations. Therefore, according to the literature, cooperation and a sense of responsibility are essential in all stages to mitigate or remove the incentives that stimulate bypassing guards and protective devices.

Table 4.9 Frequency of solutions to prevent bypassing in various phases

Phases	**Codes**	**N**	**%**
Design	S2- S3- S6- S9- S11- S12- S14- S15- S16- S19- S21- S27- S28- S29- S49- S50- S53- S57- S59- S62- S72- S73- S74- S75- S76- S77- S78- S79- S81- S82	30	36.585
Manufacturing	S5- S8- S13- S43- S44- S45- S46- S58- S60- S61- S69- S71- S80	13	15.854
Usage by enterprises as end users	S1- S4- S7- S10- S17- S18- S20- S22- S23- S24- S25- S26-S30- S31- S32- S33- S34- S35- S36- S37- S38- S39- S40- S41- S42- S47- S48- S51- S52- S54- S55- S56- S63- S64- S65- S66- S67- S68- S70	39	47.561
TOTAL		82	100

In another classification scheme, HSE (2000) introduced human factors at work as a key component in decreasing the amount of accidents and work-related disorders. To view human factors, that study has considered job, individual, and organizational perspectives. According to (Reason, 2016), individual, engineering, and organizational models have been introduced as three approaches for safety management. Hence, in the following, these concepts are expressed and another distribution (apart from Table 4.9) of recommendations is organized to stop the practice of defeating.

- *Technical factors:* suggestions related to physical and non-physical components and their design in the workplace such as machine, tool, software, process, or tasks to prevent defeating (e.g. Ergonomic design, which is undesirable, should be improved; installing “video cameras” on CNC machines or the use of “better quality glass” that would help operators monitor working process, and more.)
- *Organizational factors:* suggestions associated with influencing components in organizations to establish health and safety culture at all levels to promote the use of guards and protective devices in enterprises (e.g. providing appropriate supervision that has influence in overriding safety systems, having consequences for the undisciplined actions, to just name a few.)
- *Individual factors:* suggestions related to human performance that have a positive influence in changing habits or promoting individual characteristics, such as skills and attitudes to avoiding bypassing in a work area (e.g. raising awareness, ensuring that safeguards are reinstated before operating the equipment, and more.)

Table 4.10 Frequency of solutions to prevent bypassing based on influential factors

Influential factors	Codes	N	%
Technical	S2- S3- S5- S6- S8- S9- S11- S12- S13- S14- S15- S16- S18- S19- S21-S27- S28- S29- S43- S44 -S45- S46- S49- S50- S53- S57- S58- S59-S60- S61- S62- S63- S68- S69- S71- S72- S73- S74- S75- S76- S77-S78- S79- S80- S81- S82	46	56.098
Organizational	S1- S4- S7- S10- S17- S20- S22- S23- S24- S25- S26- S30- S32- S34-S35- S36- S37- S38- S39- S40- S41- S42- S47- S48- S52- S54- S55- S64- S65- S66- S67- S70	32	39.024
Individual	S31- S33- S51- S56	4	4.878
TOTAL		82	100

Table 4.10 illustrates the categorization of solutions in the literature based on the factors of influence for preventing bypassing in enterprises. Technical factors referred in collected recommendations play a major role (56.098%) and 39.024% of solutions suggested by researchers are directed at organizational factors. Finally, 4.878% of proposals are associated with individual factors and are the least considered in preventing the defeating of guards and protective devices.

4.8 Conclusions

Bypassing guards and protective devices can have harmful consequences for individuals and organizations. Doing so can lead to both reversible and irreversible damage, such as injuries or fatalities for operators, and it can result in monetary losses for the organization as a result of production shut down, equipment damage, material loss and fines for regulatory violations. The definitions of overriding guards and protective devices were presented, and then the standards and regulations that require employers and employees to provide and use the guards and protective devices were studied. Twenty-two references in the literature that investigate occupational accidents stated that this behaviour contributed to a significant proportion of accidents (as illustrated in Table 4.4). Analysis of the contributory causes of accidents, as reported in the papers reviewed, demonstrated that the manipulation of safety devices is widespread in industry. This research performed a state of the art to investigate the incentives for bypassing guards and protective devices and then assessed the preventive solutions to avoid bypassing safety measures. Scholarly and experimental documents were reviewed in this process. A summary of the findings is presented below:

- Seventy-two incentives were extracted from various studies.

- In the literature, the most frequent incentives included being able to perform activities, such as adjustments, troubleshooting, maintenance and installation, the lack of visibility, failures and poor reliability of the safeguards, production disturbances, the need to work faster or to obtain greater productivity, the lack of management commitment, disabling the safeguards was easy, working is more convenient without them, poor ergonomics and poor human-machine interface, operators who believe safeguards are a luxury, a lack of knowledge about the risks, underestimation of the risks, safeguards that slow down production, safeguards that are difficult to use, a lack of disciplinary consequences and time-saving incentives.
- The following categories were identified as the origins of the motives for bypassing safety measures: productivity, ergonomics, machine or safeguarding, behavior and corporate climate. The evidence shows that designing and manufacturing suitable machines and devices plays a key role in reducing or eliminating bypassing.
- In the first 16 rankings, the incentives linked to employees' behaviours play a minor role. This shows that the authors of the studies reviewed believe that bypassing is not just an operator failure.

Furthermore, recommendations to prevent overriding guards and protective devices were analyzed from the literature. These are summarized below:

- Eighty-two solutions were reported in various studies
- An assessment matrix (IFA, 2011), a checklist for machinery purchase (DGUV, 2013), and a checklist to stop the manipulation of protective devices (Suvapro, 2007) were developed as tools to prevent and eliminate bypassing. Moreover, a website (Stop-defeating) has provided guidelines for manufacturers, suppliers and users to prevent defeating. The rest of the studies only proposed preventive suggestions; they did not recommend the use of any tools.
- In terms of recommendations for the design, manufacturing and usage phases, more varieties of solutions were presented for the usage phase than the two other phases.
- Influential factors in reducing or removing manipulation in industries are technical, organizational and individual in nature. Most recommendations to prevent bypassing have focused on technical factors. Organizational factors were ranked second and individual factors played a minor role.

Overall, this paper includes a review of the majority of papers and other documents that are available in library databases. It provides a comprehensive analysis of the incentives for bypassing and suggestions to promote the use of guards and protective devices in industry. Furthermore, this study provides useful insights into the definitions of bypassing, regulations associated with bypassing, incentives to bypass, and suggestions for improvement for researchers and OHS preventionists in enterprises. Finally, this study's findings will promote future research in this area. It can also be applied to improving the use of guards and protective devices. In addition, the study contributes to providing a complete picture of bypassing in order to develop a holistic tool to prevent circumvention. That tool will be holistic because it will help identify the risk of bypassing through an examination of the categories identified in the analysis of the literature - ergonomics, productivity, machine or safeguarding, behavior, and corporate climate - in contrast to existing tools that deal with only machinery and safeguards. Thanks to this analysis of the literature, the intended tool will also include solutions to mitigate the risk of bypassing based on the three categories of influential factors that have been identified: technical, organizational and individual. The tool will be addressed in future research, as Reason (2000) encourages a system-focused approach instead of a person-focused approach that blames individuals.

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CHAPTER 5 ARTICLE 2: A HOLISTIC ASSESSMENT TOOL TO ESTIMATE THE PROBABILITY OF BYPASSING SAFEGUARDS ON MACHINERY

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Abstract

Bypassing safeguards is a contributing cause of work-related accidents. Organizations must pay attention to the incentives of bypassing and ways to prevent it. This paper proposes a holistic assessment tool that estimates the probability of bypassing safeguards on machinery as high, significant, moderate or low based on a comprehensive list of literature-based incentives to bypass safeguards. The proposed tool is developed in four steps. Step 1 identifies all activities and operation modes associated with the machine. Step 2 investigates whether bypassing exists. Step 3 identifies and estimates the existing incentives to bypass. Step 4 estimates the probability of bypassing to help occupational health and safety (OHS) practitioners determine the corrective and preventive actions to promote the use of safeguards in industries. The tool is tested with five scenarios. Some of the results illustrate that: (i) OHS practitioners could identify the existing incentives in enterprises among a comprehensive list of incentives presented in the tool; next, they could determine the impact of the incentives; (ii) OHS organizations and practitioners from enterprises with limited resources could prioritize improvement actions to reduce or eliminate the incentives to bypass based on the probability levels estimated with the tool. The bypassing issue should be integrated with the elements of the OHS management system in organizations to promote the use of safeguards and to reduce accidents due to bypassing of safeguards on machinery.

Keywords: Bypassing, Guards and protective devices, Assessment tool, Manufacturing systems, Machine safety, Continuous improvement

5.1 Introduction

Risk reduction measures are applied in the risk management process to reach an acceptable risk level. Those measures help prevent accidents and provide a safe workplace. Bypassing guards and protective devices on machinery has been observed as a widespread problem in enterprises. Twenty-two papers dealing with machine-related accidents reveal that bypassing is one of the main contributing factors in the occurrence of accidents in different sectors of industry (Haghighi, Chinniah, et al., 2019). For example, Freedman (2004) mentioned that bypassing safeguards on machinery in automated production is one of the most common contributory causes of accidents. Machine guarding was not used in woodworking and metalworking industries that were involved in two-thirds of amputation incidents in Minnesota, USA, from 1995-1997 (Samant et al., 2006). One study from Germany has revealed that almost 37% of the protective devices on metalworking machines were permanently (14%) or temporarily (23%) bypassed (Apfeld et al., 2006). Furthermore, Apfeld (2010); Lüken et al. (2006) reviewed the German report and highlighted that 25% of machine-related accidents occurred due to defeated protective devices. In addition, 34% of companies with metalworking machines experienced bypassing. In 2008, there were more than 10000 accidents and eight deaths due to bypassing protective devices (Apfeld, 2010). In Switzerland, Suva[16] found that protective devices on machinery and automatic facilities are defeated in approximately half of the 300 companies (Zimmermann, 2007). This situation has entailed fatalities and serious injuries such as amputations, crushes, fractures and others. All of this evidence demonstrates the significance of the bypassing issue. In light of this, we present a new assessment tool dedicated to organizations or occupational health and safety (OHS) practitioners in enterprises that use machinery. The tool will help them identify the incentives to bypass in their workplace and to estimate the probability of bypassing. By applying the proposed tool, they will be able to define suitable corrective and preventive measures to tackle this common problem. This new tool enables a comprehensive evaluation of the incentives to bypass to be carried out by addressing the 72 possible incentives extracted after a literature review presented in (Haghighi, Chinniah, et al., 2019).

[16] Suva is a company in Switzerland whose field of activities are prevention, insurance, rehabilitation, and the safety of working area in organizations.

The remainder of this paper is organized as follows. Sections 5.1.1 and 5.1.2 provide a review of bypassing and risk estimation tools in order to provide a better understanding of the contributions of this paper. The method is described in Section 5.2. Section 5.3 presents the proposed assessment tool. Section 5.4 analyzes bypassing scenarios to test the developed assessment tool and to show the usability of the tool for machinery in the manufacturing sector. Section 5.5 discusses the results. The final section presents the conclusions.

5.1.1 Review of bypassing safeguards

Guards and protective devices are the most efficient measures, after inherently safe design measures, in the hierarchy of risk reduction measures (ISO 12100, 2010). In the context of this paper, bypassing safeguards means removing guards or disabling protective devices on machinery. Bypassing is one of the main contributing factors in machine-related accidents in different countries in various industries (Apfeld et al., 2006; Backström & Döös, 2000; Charpentier, 2005; Charpentier & Sghaier, 2012; Chinniah, 2009, 2015a; Chinniah & Bourbonniere, 2006; Chinniah et al., 2007; Dźwiarek, 2004; Gardner et al., 1999; Hopkinson & Lekka, 2013; Huelke et al., 2006; Järvinen & Karwowski, 1993; KANbrief, 2003; Mattila et al., 1995; D. L. Parker et al., 2009; Pratt & Hard, 1998; Samant et al., 2006; Shaw, 2010; Vautrin & Dei-Svaldi, 1989; Zimmermann, 2007) and ((Edwards, 1993) cited in (Backström & Döös, 2000)).

There is limited research directly related to bypassing. Caputo et al. (2013) identified “tampering avoidance” as one of the rating factors for selecting safety devices in their Analytic Hierarchy Process (AHP) method. They concluded that safety devices should be hard to defeat. KANbrief (2003) stated that technical actions should be taken into account in machine safety standards to prevent bypassing. A German report (Apfeld et al., 2006), the first research related to bypassing protective devices on machinery, estimated the amount of defeating protective devices in the metal-working sectors in Germany by distributing and returning 940 general questionnaires. In the next phase of that study, bypassing practices and reasons for defeating were investigated on 200 machines through a special questionnaire. Finally, some solutions were discussed from psychological, ergonomic, organizational and technical perspectives. Apfeld (2010) and Lüken et al. (2006) did an overview of the German research. Bypassing is so important to tackle that Switzerland, Italy, and Germany have started reducing tampering by applying certain measures (Apfeld, 2010). Unfortunately, Apfeld (2010) did not specify what these measures were. In addition, the International Social Security Association (ISSA) started a project to consider the subject as a global issue, with the presence of Austria, Germany, Italy, and Switzerland.

In 2007, Suva launched a campaign to boost controls to stop the manipulation of protective devices (Zimmermann, 2007). The HSE[17] in the UK carried out a study to identify the human factors related to the circumvention of interlocks on Computer Numerical Control (CNC). That study explored three factors: (i) predisposing factors (e.g. training, experience), (ii) enabling factors (e.g. lack of visibility, poor flexibility, impractical guards), and (iii) reinforcing factors (e.g. disciplinary measures, management ignoring defeating) that influence an operator's behavior towards bypassing (Hopkinson & Lekka, 2013). Chinniah (2015a) analyzed 106 serious and fatal accident reports associated with the moving parts of machines in Quebec. He declared that preventing the bypassing of safeguards is one of the measures required to mitigate serious injuries and fatalities in companies with limited occupational health and safety (OHS) resources.

In 2011, IFA (2011) designed an assessment matrix by considering a summary of the benefits to bypass protective devices revealed by Apfeld et al. (2006). That matrix can only be applied by designers to evaluate the incentives to bypass a protective device. The IFA assessment matrix was accepted by the ISO/TC 199 technical committee, and published in ISO 14119 (2013) as an informative guide to assess the motives of defeating interlocking devices. Suvapro (2007) proposed a checklist to stop defeating protective devices that could control the hazards of bypassing as a general tool. The checklist contains the questions related to (i) new machine purchases, (ii) normal functions, (iii) specific functions and maintenance, (iv) human behavior, training and organization to control the hazards of bypassing and to define the measures for preventing manipulation. A checklist was designed by DGUV (2013) only focusing on the purchase phase of the machine, procuring machinery with the minimum incentives to bypass protective devices. In addition, the stop-defeating.org website was launched to provide guides that are applicable for manufacturers, suppliers and users. It also helps prevent defeating safeguards on machinery and share related discussions and information within companies. Therefore, each of the above-mentioned tools contributes to tackling the bypassing issue, even though one of these includes limited incentives for the evaluation in the design phase (the IFA

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[17] Health and Safety Executive (HSE) is a body in Great Britain that provides advice, guidelines, news, tools, publications, regulations, and research related to occupational health, safety, and illness to support organizations.

assessment matrix) and another just focuses on the machine procurement step (the DGUV checklist). All of these present some recommendations or general information for industries.

Because of the importance of the bypassing issue, some standards take prevention into account at the design phase of a machine. For instance, guards and protective devices are designed such that they cannot be easily rendered inoperative or bypassed (CSAZ432, 2016; Le parlement européen, 2009). The defeating of electro-sensitive protective equipment should be avoided (ISO 13855, 2010). The protective effect of the two-hand control device should be difficult to circumvent (ISO 13851, 2002). The circumvention possibility of protective measures should be considered during risk estimation (ISO 12100, 2010). As such, the latest version of ISO 14119 (2013) provides the required preventive measures to reduce the possibility of defeating interlocking devices. In addition, it contains an informative guide for evaluating the benefits of bypassing interlocking devices on the basis of the assessment matrix proposed by IFA (2011), which was mentioned earlier.

None of the previous studies have presented a holistic tool that deals with the aspects that influence bypassing, beyond just the equipment. Lack of management commitment, worker’s habit and lack of disciplinary actions are some examples not considered by other tools. Hence, to fill that gap, this paper introduces a holistic tool comprised of 72 possible incentives to bypass classified into five main categories: 1) ergonomics, 2) productivity, 3) machine or safeguarding, 4) behavior, and 5) corporate climate based on the literature review that Haghighi, Chinniah, et al. (2019) recently carried out on the incentives to bypass and the preventive suggestions for this issue. In addition, according to the extracted recommendations, they state that preventing bypassing should be taken into account in the design, machine manufacturing, and usage phases by considering technical, organizational, and individual factors as the influencing factors.

5.1.2 Review of risk estimation tools

Since the proposed tool is about estimating the probability of bypassing, a review of some OHS-related risk estimation tools was considered relevant in order to inform the choice of risk parameters as well as the number of levels describing the parameters and the risk. Chinniah et al. (2011) and Gauthier et al. (2012) studied 31 risk estimation tools related to the safety of industrial machines. The authors presented several construction rules. For instance, they recommended considering between three and five levels for every risk parameter and using no less than four risk levels as the optimal number of levels. In addition, (Chinniah et al., 2018) tested six risk estimation tools and confirmed the effect of construction flaws in the architecture of the tools. Other authors have developed new estimation tools. Moatari-Kazerouni et al. (2015) developed an OHS risk estimation tool for manufacturing systems that was then validated by 20 hazardous scenarios. Burlet-Vienney et al. (2015) proposed a risk assessment tool for confined spaces applied to accident scenarios before final validation with 22 safety professionals. Jocelyn et al. (2016) presented a new methodology that integrates dynamic experience feedback into machinery-related risk estimation. Testing the methodology with two accidents elucidated its feasibility. Azadeh-Fard et al. (2015) introduced a three-dimensional risk assessment matrix including the severity, frequency, and preventability of an incident. The new method was applied to a case study with real data. All of the presented estimation tools are applied to scenarios or accidents as case studies to ensure their appropriateness.

In the light of the above, the incentives to bypass safeguards[18] need to be identified in enterprises in order to consider suitable corrective and preventive measures to reduce or eliminate the incentives. The objective of this paper is therefore to propose a holistic assessment tool that estimates the probability of bypassing safeguards on machinery based on a wide scope of incentives to bypass safeguards. The proposed tool is holistic because it not only addresses the incentives related to the machine and safeguarding, but it also encompasses incentives associated with ergonomics, productivity, behavior and corporate climate aspects, contrary to the existing tools mentioned in Section 5.1.1.

5.2 Method

The new assessment tool is adapted from the assessment matrix developed by IFA (2011) based on the findings of Haghighi, Chinniah, et al. (2019) related to the 72 incentives to bypass safeguards extracted from reviewed studies. The complete list of incentives in each category is presented in Appendix C. The latter provides a concise or equivalent version of each description of an incentive from Haghighi, Chinniah, et al. (2019) in order to increase the readability of the paper. Figure 5.1 depicts the process for designing and testing the proposed assessment tool.

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[18] According to (ISO 12100, 2010), the “safeguard” term addresses guards and protective devices.

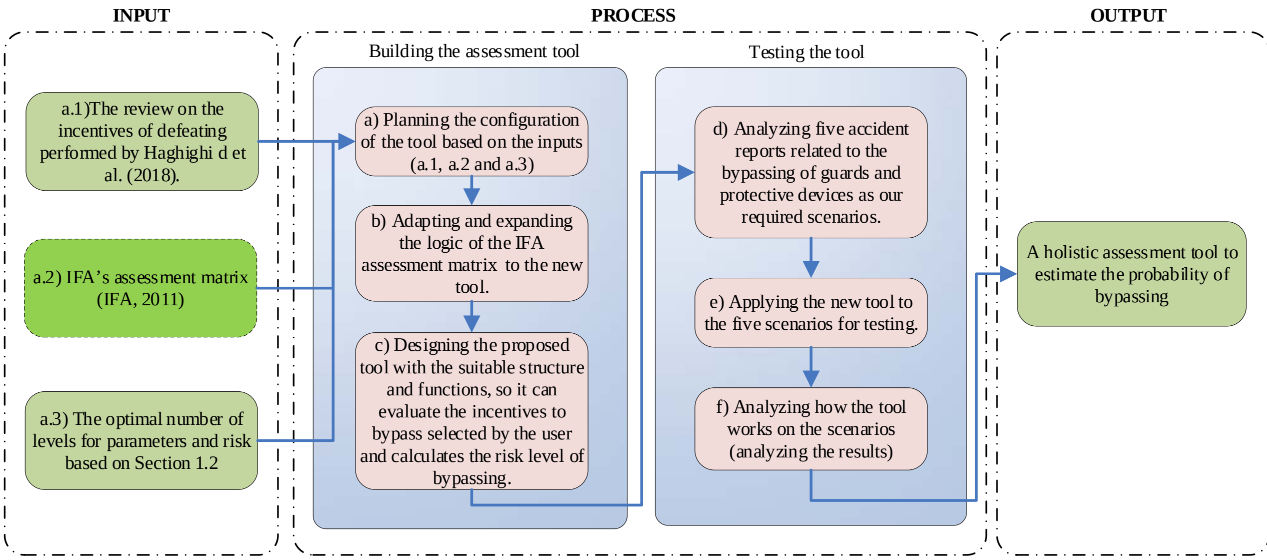

Figure 5.1 A flow diagram of the methodology used to develop the proposed assessment tool

The second input (a.2) in Figure 5.1 is drawn with a dotted line to show the difference from the other elements of the flow diagram. The IFA assessment matrix (IFA, 2011) was developed for designers to identify the benefits that may exist without the presence of protective devices. After defining the tasks and relevant modes of operation, the matrix asks two questions: 1) is the task feasible in the determined mode of operation? and 2) can the task be performed without defeating? "Yes" or "No" options are offered to answer those questions. In the next step, a summary of the incentives in the HVGB report (Apfeld et al., 2006) is considered. Three possible entries, including "no benefit," "minor benefit" and "significant benefit" are offered to determine whether there is a benefit to performing each task without the presence of protective devices. A benefit would be marked with one of those entries if the "Yes" option is selected for the first two questions noted above.

Finally, the IFA assessment matrix defines three levels, but this time for the incentive to bypass:

- "Low": no benefits for a task.
- "Present": at least one minor or significant benefit for a task.
- "High": the task is not permissible in the operating mode or the task is impossible without defeating. Therefore, improvements are essential in the machine design.

Since the IFA assessment matrix inspired the design of the proposed tool, the latter adapts the formula that IFA (2011) used for its assessment matrix (see Section 5.3.4 for more detail). In addition, the new tool is comprised of four levels indicating the probability of bypassing, while the incentive to bypass (ITB) is described in the three levels of the IFA assessment matrix.

5.3 Designing the assessment tool

Sections 5.3.1-5.3.4 present the steps for developing the new assessment tool. The latter is designed and executed with Excel spreadsheet software. The OHS practitioner needs to fill out one worksheet for each machine in the company.

5.3.1 Step1: Identification of activities and operating modes

When OHS practitioners in enterprises use the proposed tool, they would have to identify the existing incentives (potential or current incentives) for bypassing that could take place in their workplace. By understanding the incentives, they could determine suitable corrective actions to reduce or eliminate bypassing and to prevent its recurrence. Therefore, to evaluate the incentives to bypass safeguards on machinery, all of the activities implemented on the machine should be listed. That list should be accurate and cover all activities in the machine lifecycle to help the OHS practitioners have as precise of an assessment as possible. Each row of the Excel worksheet is assigned to one activity, as illustrated in the first column of Figure 5.2. Table 5.1 suggests a list of possible activities as a user guide for the "activity" column in Figure 5.2; the users can select their desired activity. That list is based on Apfeld (2010), Chinniah et al. (2007), IFA (2011), ISO 12100 (2010) and ISO 14119 (2013). However, in real life, OHS practitioners can adapt the activity list with the participation of operators.

According to machine design, there are different machine operation modes for carrying out the activities. Various operation modes should be identified and entered in corresponding columns A to C in Figure 5.2. In those columns, the modes of operation can be selected with an asterisk (*) as manual, automatic or something else. The "Activity" and "Operation modes" are the initial data input areas to acquire the knowledge about the machine and to start the assessment. Afterward, the existing safeguards (Figure 5.2- column D) for each activity should be written in the column assigned to this data (note: the OHS practitioner can assign more than one safeguard to an activity). Figure 5.2- column E includes a question for asking about the situation of bypassing (see Section 5.3.2 for details). Columns F to T in Figure 5.2 are the possible incentives classified into five main categories including ergonomics, productivity, behavior, machine or safeguarding, and corporate climate (more detail is available in Section 5.3.3). Those incentives are numbered from I1 to I72 according to Appendix C. The last column on the right in Figure 5.2 aims to show the results of estimating the probability level of bypassing (see Section 5.3.4 for further explanation).

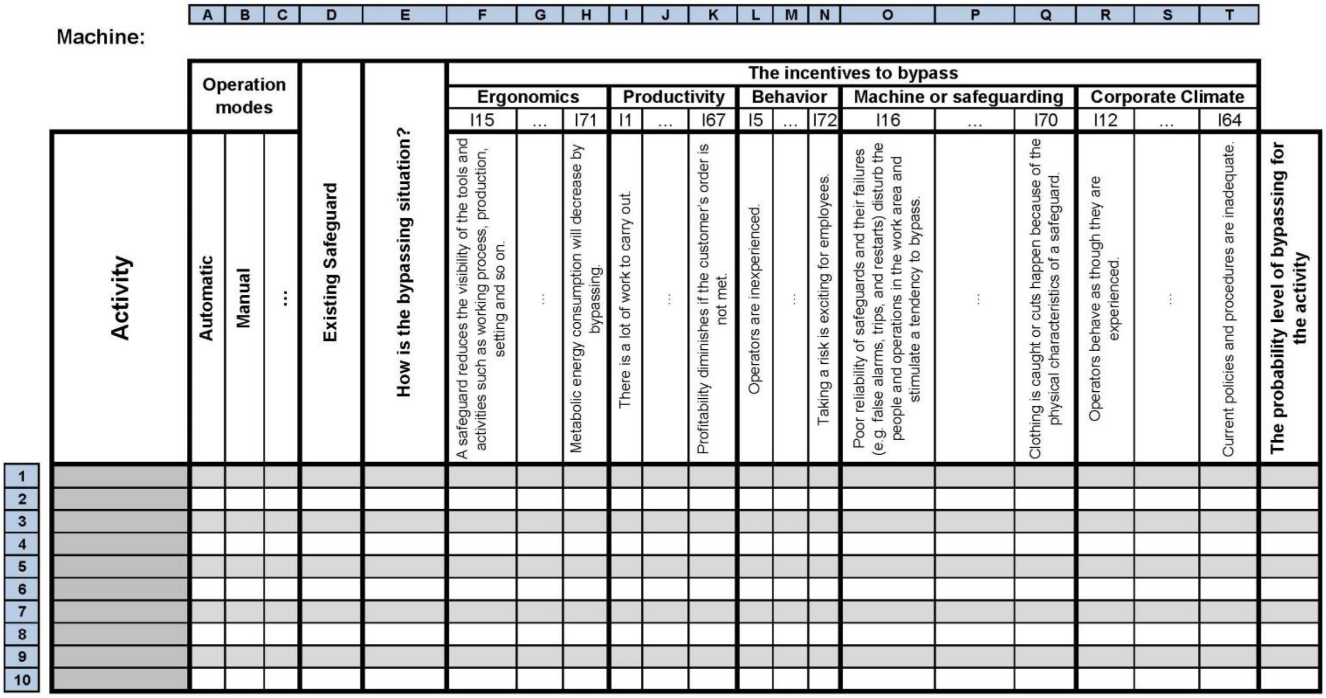

Figure 5.2 The proposed assessment tool to identify the incentives and estimate the probability of bypassing

Table 5.1 The list of activities applicable to the proposed assessment tool

	Activities
Setting	Parameter verification (e.g. force, speed, pressure)
	Programming
	Functional Testing
	Commissioning
	Tool exchange
Operation	Loading raw material
	Processing/ machining
	Process monitoring/ Supervision/ Visible control/ Inspection
	Random sampling and checking
	Work piece exchange
	Interventions during operation (e.g. removing waste, materials, remove blocked material, cleaning, swarf removal)
	Adjustment and settings of parameters during operation (e.g. speed, pressure, force)
	Interventions during operation for measuring
	Verifying the final product
	Unloading the product from the machine
	Stopping the machine in case of emergency
	Restart after unscheduled stop / Recovery of operation (from e.g. jam or blockage)

Table 5.1 The list of activities applicable to the proposed assessment tool (continued)

	Activities
Maintenance	Stop the machine Cleaning Troubleshooting on the machinery Troubleshooting on the workflow Corrective maintenance/ rectification of faults/ repair Preventive maintenance Greasing, Lubricating Dismounting parts Replacement of tools Isolation and energy dissipation Restart machine after stopping and finishing maintenance

5.3.2 Step 2: Investigation of the existence of bypassing

To begin the assessment, a question is raised as follows, in Figure 5.2, column E:

- How is the bypassing situation?

Three possible entries are defined for this question, as described in Table 5.2. “A” is marked for the incentive that exists and is observed in the enterprise. The other entry, “B,” is to show that while bypassing does not occur, there are some potential incentives for it to happen in the future. “C” is marked when there are no incentives.

Table 5.2 Proposed entries for bypassing relative to the existence of incentives

Entries	Description
A	The safeguard is bypassed and the OHS practitioner in the enterprise notices actual incentives to take corrective measure.
B	The safeguard is not bypassed, but the OHS practitioner in the enterprise observes some potential incentives. That may cause bypassing in the future.
C	There are no incentives to bypass.

5.3.3 Step 3: Identification and estimation of existing incentives to bypass

In the proposed tool, the 72 incentives and their corresponding categories constitute columns F to T in the worksheet. Three levels (Table 5.3) are considered to estimate the impact of the incentives on the probability of bypassing inspired by the entries defined in IFA (2011) and ISO 14119 (2013). Each of these levels can be assigned to a corresponding incentive for carrying out the activity.

Table 5.3 The possible levels describing the effect of incentives to bypass

Entries	Description - the effect level of the incentive
0	No effect due to the nonexistence of an incentive.
+	Slight effect of an incentive on the probability of bypassing.
++	Significant effect of an incentive on the probability of bypassing.

The possible entries mentioned in Table 5.3 for the effects of incentives will be explained later in Section 5.4. That explanation and the examples will clarify our approach to determine the level of the effect of an incentive. Provided that an OHS practitioner wants to estimate the probability of bypassing with the proposed tool, he or she is aware of the working conditions in the enterprise where he or she works. Therefore, he or she should be able to recognize a suitable effect level of incentives on the basis of existing strengths and shortcomings of the organization to achieve a more accurate probability estimation for bypassing. The latter would provide a foundation for prioritizing the preventive measures that would be able to manage bypassing.

5.3.4 Step 4: Estimation of the probability of bypassing

After filling out the proposed tool with the above-mentioned data, which are required to estimate the probability of bypassing, the following concepts are applied to determine the probability level of bypassing for each activity (Table 5.4). We considered four levels for the probability of bypassing to attain more precise results for prioritization, as per Chinniah et al. (2011) and Gauthier et al. (2012), who proposed at least four levels of risk to avoid overestimating risks. As such, three and five levels for parameters to be compatible with the most of risk estimation tools.

To consider the data that an OHS practitioner entered into the tool, the Excel function presented in Figure 5.3 generates a corresponding probability level of bypassing.

The probability level ranking helps decision makers in enterprises prioritize the corrective actions to reduce and eliminate bypassing safeguards. Therefore, the enterprises can have continuous improvement to change their current workplace conditions and to provide a safer workplace for employees with minimum incentives for defeating.

Table 5.4 Proposed levels for the probability of bypassing for an activity

Level	Description - The interpretation of the probability levels of bypassing	
	Corresponding answers to the question from step 2	The incentives to bypass
High	A	Half or more than half of the incentives identified for the activity have a significant effect (++) on the probability of bypassing.
Significant	A	Fewer than half of the incentives identified for the activity have a significant effect (++) on the probability of bypassing.
Moderate	B	There is at least one incentive identified for the activity that has a slight effect (+) or significant effect (++) on the probability of bypassing.
Low	C	There is no reasonably foreseeable incentive for the activity (0).

```
=IF(AND(COUNTA(A1:C1)>0,D1<>""),IF(E1="C","Low",IF(E1="B","Moderate",IF(E1="A",IF(COUNT(F1:T1)<COUNTA(F1:T1),IF(COUNTIF(F1:T1,"++")>=((COUNTA(F1:T1)-COUNT(F1:T1))/2),"High","Significant"),""),""))),"")
```

Figure 5.3 Function applied to estimate the probability level of bypassing in the Excel spreadsheet.[19]

5.4 Testing the assessment tool

The feasibility of the proposed assessment tool to identify the incentives of defeating and to estimate the probability of bypassing is tested with five bypassing scenarios related to accidents: scenarios V to Z. Four of those accidents (CNESST, 1990, 2006, 2007, 2008) are available in the accident report database of the *Commission des normes, de l'équité de la santé et de la sécurité du travail* (CNESST, www.cnesst.gouv.qc.ca). The other case is from the *National Institute for Occupational Safety and Health*'s accident database (NIOSH, 2004). The following two scenarios, one from NIOSH and the other selected among the accident reports from CNESST, are taken as examples to explain how the tool is tested through bypassing scenarios.

[19] Please see Appendix D for more clarification.

5.4.1 Scenario V: bypassing safeguards on an automated knitting machine

Table 5.5 describes a summary of an accident related to bypassing involving a knitting machine.

Table 5.5 Scenario V- Summary of a bypassing practice (NIOSH, 2004)

Manufacturing sector	Textile factory
Machine	Automated knitting machine
Existing safeguards	Interlocking guard (each guard was equipped with a safety interlock switch) and the three colored buttons, including green, red, and yellow, control the machine.
Activity	The machine was not gathering the fabric correctly. The worker had to shut off the machine to access the fabric to make an adjustment and to fix the problem.
The method of bypassing	The operator jammed a sewing needle in the green button (“on”) that turned the machine on. Therefore, the machine could continue the operation with the guards open.
Flaws from the accident report identified as incentives to bypass	(a) There was no training program emphasizing the dangers of defeating (b) There were no written safety programs or written safety instructions for the workers using the knitting machine. (c) Defeating was a common action in the company. (d) The company’s president was aware of the occurrence of defeating, but did not take any action to stop it. (e) The victim knew how to defeat the safety device. (f) The operator bypassed the interlocking guard to make an adjustment. (g) Inadequate programs of: supervision, rewards, and disciplinary actions (these kind of programs to assure safe working method is recommended in the accident report).
Consequence	Death as a result of being crushed by the moving parts of the machine.

The corresponding incentives in the proposed tool are selected for each flaw extracted from the accident report (Table 5.6). The selection of corresponding incentives in the proposed tool is either on the basis of the facts from the evidence and the analysis of causes in the accident report, or from our interpretation of the accident report. For instance, the accident report claims "the victim's co-workers admitted that this [bypassing] was a common practice in the industry." Accordingly, our analysis linked that claim to the employees' habits and consequently to the organization's culture of safety. Therefore, for the flaw (c) mentioned in Table 5.5, we selected I63 and I46 from Appendix C as their corresponding incentives in the proposed tool (see Table 5.6).

Table 5.6 Selection of corresponding incentives in the tool for the flaws in scenario V

Flaws extracted from the accident report	Incentive code * - The corresponding incentives in the proposed tool - Effect level
(a)	I51- There is a lack of adequate training and awareness about manipulation (++)
(b)	I64- Current policies and procedures are inadequate (++)
(c)	I63- The issue of defeating is not integrated into a culture of safety (+) I46- Bypassing is a habit (++)
(d)	I36- There is a lack of management commitment and managers ordered, tolerated, encouraged or ignored circumvention (++)
(e)	I17- Safeguards can be disabled easily and with little effort (++) I29- Easy access to software and switches make safeguards possible to defeat (++)
(f)	I19- Safeguard removal is necessary to perform activities such as adjustments, troubleshooting, maintenance, and installation (no specific operation modes exist for performing them) (+)
(g)	I60- There is no supervision that monitors if a safeguard is enabled (+) I37- There are no enforcement or disciplinary actions for those who bypass safeguards (+)

*The code of an incentive comes from Appendix C.

The aforementioned data is applied to the proposed tool. Seven flaws are extracted by analyzing the accident report and their corresponding incentives in the tool are identified (there are ten incentives in the tool).

Afterwards, the effect levels are selected for the incentives. Hence, this paragraph explains the possible entries in Table 5.3 by using some existing incentives in scenario V as an example. The accident report of that scenario mentions, "the company did not have a written safety program. There were no written instructions on safety for the employees using the knitting machines." It also mentions, "the company did not have a training program. The training should also stress the danger of over-riding the safety features." These statements are concrete facts in the accident report that demonstrate flaws corresponding to some of the 72 incentives as illustrated in Table 5.5. The occurrence of the accident is evidence of the fact that the enterprise took no action before tackling the situation. Therefore, we consider these flaws as incentives with a significant effect on the probability of bypassing (++). In addition, in the accident report, we observed a recommendation for programs of "supervision, rewards, and progressive disciplinary measures" to ensure safe working methods. There were no facts directly related to the absence of supervision and disciplinary measures in the accident investigation and they were only mentioned in the recommendations. Thus, we interpreted that the company needs to make improvements in supervision and disciplinary actions. Eventually, since those points were not facts, we consider them to be incentives to bypass that have a slight effect on the probability of bypassing (+).

According to the explanation of the possible levels of the incentive effect listed in Section 5.3.3 and the examples stated above, the suitable level of effect is marked for each incentive as shown in Table 5.6. Six of the incentives have a significant effect (++) and four of them have a slight effect (+) on the probability of bypassing. The rest of the 72 incentives are not present in this accident report; therefore, they are marked (0) in the tool. Bypassing occurred in this accident; thus, the incentives exist and the answer to the question in the tool would be "A". Moreover, the number of the (++) is more than half of the identified incentives. Finally, the level of probability estimated for the activity would be "High" according to the different probability levels defined in Table 5.4. Figure 5.4 illustrates the identification of the incentives to bypass and the probability of bypassing estimated for the manual troubleshooting activity on the knitting machine in scenario V.

5.4.2 Scenario Y: bypassing safeguards on an extruder

The process of extracting the flaws from an accident report (scenario Y) and deciding on the corresponding incentives for each flaw are carried out, as we have explained in Section 5.4.1 for scenario V. Table 5.7 describes a summary of the accident related to bypassing involving an extruder. Table 5.8 shows the selected corresponding incentives for each flaw in the scenario. Three safeguards, including interlocking movable guards, the mesh enclosure and pressure-sensitive mat, are bypassed. Therefore, during the identification of the incentives throughout the accident report, we associated each incentive to each existing safeguard, according to our own interpretation. As such, the incentives are marked with the relevant safeguards in Table 5.8.

Table 5.7 Scenario Y- Summary of a bypassing practice (CNESST, 2007)



Manufacturing sector	Plastics industry (manufacturing of plastic products)
Machine	Extruder
Existing safeguards	- Four interlocking movable guards with locking devices, two in the front and two in the back of the molding zone. Hydraulic switches (valves) are also present at each of the interlocking movable guards of the extruder. - The above-mentioned interlocking movable guards had been replaced with a mesh enclosure. - A pressure-sensitive mat has also been placed in front of the molding area so as to interrupt the movement of the molds if an operator enters the danger zone during operation of the equipment.
Activity	- The mechanic supervisor was making production adjustments (setup) and changing molds to start new production. During these adjustments, he was manually removing defective pieces, incomplete pieces and accumulated plastic from the mold.
The method of bypassing	- The front interlocking movable guards were replaced with a mesh enclosure. The interlocking movable guards at the rear of the extruder were in place but their windows were broken and the access to the danger zone was possible. The locking devices of the interlocking movable guards were bypassed. Steel sheets were attached to the extruder frame to keep the actuating arm of the locking devices in the activated position. In addition, pins had also been placed to hold the hydraulic circuit valves on the interlocking movable guards, which control the movement of the molds in the pushed position, and therefore are activated at all times. - The mesh enclosure was completely removed from the workplace after a few years of use. - The pressure-sensitive mat installed in front of the molding area was missing because it was defective. A bypass connection was made in the mat control box to simulate its presence in the PLC circuit and thus to allow the use of the

machine without constraint.

Flaws from the accident report identified as incentives to bypass	(a) The safety devices were bypassed to access frequently into the molding zone to carry out some tasks with a trial and error approach. This approach requires the operator to frequently access the interior of the molding area to perform certain tasks, including the removal of defective products that cannot be ejected by the automatic system. (b) No safe working method had been prepared for employees when the interlocking movable guards were replaced with a mesh enclosure by the manufacturer. No written procedures or guidelines had been developed for doing adjustments and changing molds, maintenance or other operation safely. Only verbal instructions were given to the mechanic supervisors that the safety key on the control panel should be used whenever access to the danger zone is required. (c) The interlocking movable guards were not compatible with the automatic extraction mode of the pieces produced. The manufacturer replaced them with a removable mesh enclosure that surrounds the danger zone. (d) The employer, the plant manager, the procurement manager, the mechanic chief and all mechanic supervisors were aware of the internal changes on this equipment. In addition, the chief of mechanics of the company suggested to the health and safety committee that a light curtain be installed to compensate for the removal of the access doors and the protective enclosure of the extruder. The suggestion was not followed up and the employer chose not to act immediately. (e) The fact that the safety devices were all bypassed or non-functional at the time of the accident allowed the worker to access the molding area while the machine was in automatic mode. They needed to access the danger zone to remove defective parts and remove accumulated plastic. (f) The interlocking movable guards disturbed production. (g) The design of the mesh enclosure also meant that it had to be removed during mold change operations and production adjustments and in order to enable the forklift, which handles the different pieces of required equipment, to pass. (h) The absence of a procurement management program resulted in this machine being ordered with interlocking movable guards, which were incompatible with the automatic mode of the machine.

	(i) However, the mesh enclosure provided only partial protection since the mechanic supervisors had to remove it to make the mold changes and make production adjustments. (j) The company did not have any structured training program for workers. As such, no safety training had been developed for mechanic supervisors. (k) The supervision of applied working methods was practically non-existent. The mechanic-supervisors are mainly responsible for the maintenance and for starting production of the various pieces of equipment, and were therefore rarely available to supervise the working of the operators. There is no monitoring program to ensure that the safety measures of the different equipment were in place and functional. (l) The employer used verbal advice, primarily to warn workers of undesirable behaviors observed; those were not recorded in the employee's file. (m) Despite bypassing and the fact that workers had access to the danger zone during the operation of the equipment, no action took place to assess the risks related to such a practice. (n) During mold changing operations and production adjustments, the pressure-sensitive mat, which is not fixed in place, was, however, moved to allow access to the molding area. (o) The position of the locking devices may be accessible from being easily or accidentally bypassed by the operator. The installation and design of electrical switches might be such a way that they are easily accessible to the workers.
Consequence	Death from being crushed by the mold closure in the machine.

Table 5.8 Selection of corresponding incentives in the tool for the flaws in scenario Y

Flaws extracted from the accident report	**Incentive code* - The corresponding incentives in the proposed tool - Effect level**
(a)	I2- Reaching into a hazardous zone several times to do the work (+) (for all safeguards)
(b)	I64- Current policies and procedures are inadequate (++) (for all safeguards)
(c)	I26- Safeguards are difficult to use because they are impractical (++) (for the interlocking movable guards) I28- An unsuitable safeguard has been selected at the design phase, which is unacceptable for the operator (++) (for the interlocking movable guards)
(d)	I36- There is a lack of management commitment and managers ordered, tolerated, encouraged or ignored circumvention (++) (for all safeguards)
(e)	I58- There is impaired accessibility to the job and the tools (++) (for the mesh enclosure)
(f)	I14- Safeguards disturb the work process and production (++) (for the interlocking movable guards)
(g)	I55- The machine design is poor (++) (for the mesh enclosure)
(h)	I53- Employee involvement is ignored when procuring machines or other OHS issues (++) (for all safeguards)
(i)	I19- Safeguard removal is necessary to perform activities such as adjustments, troubleshooting, maintenance, and installation (no specific operation modes exist for performing them) (++) (for the mesh enclosure)
(j)	I51- There is a lack of adequate training and awareness about manipulation (++) (for all safeguards)
(k)	I60- There is no supervision that monitors if a safeguard is enabled (++) (for all safeguards)
(l)	I37- There are no enforcement or disciplinary actions for those who bypass safeguards (+) (for all safeguards)
(m)	I7- There is a lack of knowledge on the hazards, the severity of consequences or the risks due to the defeating of safeguards (+) (for all safeguards) I8- The risk of bypassing is underestimated or overlooked (+) (for all safeguards)
(n)	I58- There is impaired accessibility to the job and the tools (+) (for the pressure-sensitive mat)
(o)	I29- Easy access to software and switches make safeguards possible to defeat (+) (for the mesh enclosure and pressure-sensitive mat)

*The code of an incentive comes from Appendix C.

The aforementioned data is applied to the proposed tool. Fifteen flaws, extracted by analyzing the accident report and their corresponding incentives in the tool, are identified (there are 16 incentives in the tool). Twelve, thirteen and eleven incentives are, respectively, related to the interlocking movable guards, mesh enclosure and pressure-sensitive mat. According to the explanation of the possible level of effect of the incentive and the example given in Section 5.3.3, the suitable level of effect is marked for each incentive as shown in Table 5.8. Eight, eight and five of the incentives to bypass the interlocking movable guards, mesh enclosure and pressure-sensitive mat, respectively, have a significant effect (++), while four, five and six have a slight effect (+) on the probability of bypassing. The remaining 72 incentives are not present; thus, they have no effect (0) on the probability of bypassing. Since bypassing took place in the accident, the incentives exist and the answer to the question in the tool would be “A”. Moreover, the number of the (++) for interlocking movable guards and mesh enclosure represent half of the identified incentives and for the pressure-sensitive mat, fewer than half of the identified incentives. Finally, the level of probability estimated for the activity with defeated interlocking movable guards or mesh enclosure would be “High” whereas it would be “Significant” for a defeated pressure-sensitive mat according to the different probability levels defined in Table 5.4. Figure 5.5 illustrates the identification of the incentives to bypass and the probability of bypassing estimated for the manual change of tools, production adjustment and manual removal of defective pieces, incomplete pieces and accumulated plastic activity on the extruder in scenario Y.

The same process, explained in Section 5.4, is performed for Scenario W (CNESST, 1990), Scenario X (CNESST, 2006), and Scenario Z (CNESST, 2008).

Machine: Automated knitting machine

Activity	Operation modes			Existing Safeguard	How is the bypassing situation?	The incentives to bypass: Ergonomics			Productivity					Behavior					Machine or safeguarding						Corporate Climate									The probability level of bypassing for the activity
	Automatic	Manual	…			I15	…	I71	I1	…	I19	…	I67	I5	…	I46	…	I72	I16	I17	…	I29	…	I70	I12	I27	I36	I37	I51	…	I60	I63	I64	
						A safeguard reduces the visibility of the tools and activities such as working process, production, setting and so on.	…	Metabolic energy consumption will decrease by bypassing.	There is a lot of work to carry out.	…	Safeguard removal is necessary to perform activities such as adjustments, troubleshooting, maintenance, and installation (no specific operation modes exist for performing them).	…	Profitability diminishes if the customer's order is not met.	Operators are inexperienced.	…	Bypassing is a habit.	…	Taking a risk is exciting for employees.	Poor reliability of safeguards and their failures (e.g. false alarms, trips, and restarts) disturb the people and operations in the work area and stimulate a tendency to bypass.	Safeguards can be disabled easily and with little effort.	…	Easy access to software and switches make safeguards possible to defeat.	…	Clothing is caught or cuts happen because of the physical characteristics of a safeguard.	Operators behave as though they are experienced.	Other individuals are involved, not just operators.	There is a lack of management commitment and managers ordered, tolerated, encouraged or ignored circumvention.	There are no enforcement or disciplinary actions for those who bypass safeguards.	There is a lack of adequate training and awareness about manipulation.	…	There is no supervision that monitors if a safeguard is enabled.	The issue of defeating is not integrated into a culture of safety.	Current policies and procedures are inadequate.	
Troubleshooting on the machinery		*		Interlocking guards	A	0	0	0	0	0	+	0	0	0	0	++	0	0	0	++	0	++	0	0	0	0	++	+	++	0	+	+	++	High

Figure 5.4 The proposed assessment tool applied to scenario V

Machine: Extruder

Activity	Operation modes			Existing Safeguard	How is the bypassing situation?	The incentives to bypass: Ergonomics				Productivity							Behavior						Machine or safeguarding									Corporate Climate												The probability level of bypassing for the activity
	Automatic	Manual	…			I15	…	I58	I71	I1	I2	…	I14	I19	…	I67	I5	…	I7	I8	…	I72	I16	…	I26	I28	I29	…	I55	…	I70	I12	I27	I36	I37	…	I51	I52	I53	…	I60	I63	I64	
						A safeguard reduces the visibility of the tools and activities such as working process, production, setting and so on.	…	There is impaired accessibility to the job and the tools.	Metabolic energy consumption will decrease by bypassing.	There is a lot of work to carry out.	Reaching into a hazardous zone several times to do the work.	…	Safeguards disturb the work process and production.	Safeguard removal is necessary to perform activities such as adjustments, troubleshooting, maintenance and installation (no specific operation modes exist for performing them).	…	Profitability diminishes if the customer's order is not met.	Operators are inexperienced.	…	There is a lack of knowledge on the hazards, the severity of consequences or the risks due to the defeating of safeguards.	The risk of bypassing is underestimated or overlooked.	…	Taking a risk is exciting for employees.	Poor reliability of safeguards and their failures (e.g. false alarms, trips, and restarts) disturb the people and operations in the work area and stimulate a tendency to bypass.	…	Safeguards are difficult to use because they are impractical.	An unsuitable safeguard has been selected at the design phase, which is unacceptable for the operator.	Easy access to software and switches make safeguards possible to defeat.	…	The machine design is poor.	…	Clothing is caught or cuts happen because of the physical characteristics of a safeguard.	Operators behave as though they are experienced.	Other individuals are involved, not just operators.	There is a lack of management commitment and managers ordered, tolerated, encouraged or ignored circumvention.	There are no enforcement or disciplinary actions for those who bypass safeguards.	…	There is a lack of adequate training and awareness about manipulation.	Bypassing a safeguard is not detectable; they are usually restored or bosses cannot detect it.	Employee involvement is ignored when procuring machines or other OHS issues.	…	There is no supervision that monitors if a safeguard is enabled.	The issue of defeating is not integrated into a culture of safety.	Current policies and procedures are inadequate.	
Manual change of tools, production adjustments and Manual intervention for accumulated plastic removal		*		Interlocking movable guards	A	0	0	0	0	0	+	0	++	0	0	0	0	0	+	+	0	0	0	0	++	++	0	0	0	0	0	0	0	++	+	0	++	0	++	0	++	0	++	High
		*		Mesh enclosure	A	0	0	++	0	0	+	0	0	++	0	0	0	0	+	+	0	0	0	0	0	0	+	0	++	0	0	0	0	++	+	0	++	0	++	0	++	0	++	High
		*		Pressure-sensitive mat	A	0	0	+	0	0	+	0	0	0	0	0	0	0	+	+	0	0	0	0	0	0	+	0	0	0	0	0	0	++	+	0	++	0	++	0	++	0	++	Significant

Figure 5.5 The proposed assessment tool applied to scenario Y

5.5 Results and discussion

5.5.1 Results

Two bypassing scenarios (scenarios V and Y) that are from accident reports were used in Section 5.4 as two concrete examples to apply and test the tool. Three other scenarios (W, X and Z) were analyzed. However, their analysis is not detailed in this paper for the sake of remaining concise, since that analysis is similar to the analysis process described in Sections 5.4.1 and 5.4.2. Table 5.9 presents a summary of each bypassing scenario. This summary provides information about how the existing safeguards were bypassed.

Table 5.9 A summary of bypassing scenarios

Scenarios	Manufacturing sector	Machine	Activity	Safeguard	The method of bypassing
Scenario V	Textile factory	Automated knitting machine	To make an adjustment	Interlocking guards	The operator jammed a sewing needle in the “on” button.
Scenario W	Textile company	Circular knitting machine	Troubleshooting	Interlocking guards with guard locking	A piece of metal was inserted between the “start” button and the frame.
Scenario X	Concrete products manufacturing	Palletizing system	Palletizing operations	-Safety light beam -Pressure-sensitive mat	A pen cap was pushed into (wedged) the lever of the relay related to the safety light beam
Scenario Y	Plastics industry	Extruder	Production adjustments and changing molds	-Interlocking movable guards -Mesh enclosure -Pressure-sensitive mat	- Steel sheets were attached to the extruder frame to keep the locking devices of the guards in the activated position. Pins had also been placed to hold the hydraulic circuit valves, in the activated position. -The enclosure was completely removed. - A bypass connection was made in the mat control box.

Table 5.9 A summary of bypassing scenarios (continued)

Scenarios	Manufacturing sector	Machine	Activity	Safeguard	The method of bypassing
Scenario Z	Renting and other laundry services	Horizontal washing machine	Inspection	Proximity sensors	A 25¢ coin was attached with adhesive tape.

After the analysis of bypassing scenarios and flaws extracted from the accident reports, the corresponding incentives in the proposed tool were selected for all scenarios in accordance with a procedure similar to that illustrated in Table 5.6 for scenario V and Table 5.8 for scenario Y. Table 5.10 describes the results of applying the proposed tool to all scenarios as performed for scenarios V and Y throughout Figure 5.4 and Figure 5.5. Six, nine, and five flaws, respectively, are extracted from scenario W, scenario X, and scenario Z. Seven, nine (nine incentives for bypassing a safety light beam and four incentives for bypassing a pressure-sensitive mat, which are the same as incentives for bypassing a safety light beam,), and five incentives are, respectively, related to scenario W, scenario X, and scenario Z. The incentive codes in Table 5.10 and descriptions of codes are presented in Appendix E.

Table 5.10 The results of the proposed assessment tool for the bypassing scenarios

Scenarios	Existing safeguard	Answer to question	The incentives to bypass*	The probability level of bypassing for the activity
Scenario V	Interlocking guards	A	I17-I19- I29- I36- I37- I46- I51- I60- I63- I64	High
Scenario W	Interlocking guards with guard locking	A	I8-I19- I36- I46- I60- I63- I64	High
Scenario X	Safety light beam	A	I8- I16- I17- I29- I36- I46- I51- I60- I64	High
	Pressure-sensitive mat	B	I36- I46- I51- I60	Moderate
Scenario Y	Interlocking movable guards	A	I2- I7- I8- I14- I26- I28- I36- I37- I51- I53- I60- I64	High
	Mesh enclosure	A	I2- I7- I8- I19- I29- I36- I37- I51- I53- I55- I58- I60- I64	High
	Pressure-sensitive mat	A	I2- I7- I8- I29- I36- I37- I51- I53- I58- I60- I64	Significant
Scenario Z	Proximity sensors	A	I7- I17- I51- I55- I64	High

* Red= incentive with significant effect (++), Blue= incentive with slight effect (+)

5.5.2 Discussion

According to the results shown in Table 5.10, the probability level of bypassing is “high” for some scenarios while it is “significant” or “moderate” for others. None of the probability levels is “low” because all of those scenarios involve bypassing (recall that “low” refers to no reasonably foreseeable incentive for the activity). Indeed, all of the scenarios are accident reports in which bypassing safeguards was one of the contributing causes of, or factors in, serious injuries or fatalities. Therefore, the incentives to bypass safeguards exist for the activities.

An analysis of the scenarios regarding various enterprises and machines illustrates that the content adequacy of accident reports influences the analysis process. For instance, the probability estimation of bypassing for scenario Y is more detailed than scenario V. Indeed, the former comprises more incentives identified (16) than the latter (10). The brevity of the report related to scenario V and the long details in the report related to scenario Y partially explains that difference. Such a fact provides the following lesson learned: in order to optimize the accuracy of the probability estimation of bypassing, it is recommended to thoroughly get to know (describe) the work environment in order to increase the chances of identifying all or most of the reasonably foreseeable incentives to bypass. Moreover, the incentives behind bypassing, and therefore its probability estimation, can also be different depending on various work environments, individuals, machinery and processes.

Table 5.10 shows an incentive that is common among all scenarios: I64, which is related to inadequate existing policies and procedures for carrying out work safely. Other incentives, cited as follows, were present in four out of the five scenarios: a lack of adequate training and awareness about manipulation (I51), a lack of management commitment and managers ordering, tolerating, encouraging or ignoring circumvention (I36), and no supervision that monitors if a safeguard is enabled (I60). All four of these incentives (I64- I51- I36- I60) to bypass are associated with the corporate climate category. This result could help companies pay attention to incentives related to that category to promote the use of guards and protective devices. In addition, those results illustrate that the bypassing issue needs to be integrated with the occupational health and safety management system (e.g. as per ISO 45001) in an organization. Indeed, Apfeld (2010) noted that the problem of defeating was insufficiently considered throughout the occupational health and safety field. For instance, regarding the aforementioned incentives, leadership and commitment is an ISO 45001 requirement (clause 5.1) (ISO 45001, 2018), which is important in tackling OHS issues and integrating the OHS management system’s aspects into the procedures and work processes in the organization. Therefore, the manager should not ignore the probability of bypassing and should take responsibility for the prevention of serious injuries and fatalities resulting from bypassing. As such, clause 7.2 of ISO 45001 requires the provision of training for employees. Bypassing could be taken into account in training needs as one of the OHS issues in order to raise employees' awareness about the hazards of bypassing and to promote the use of safeguards in the organization. Besides, supervising the status of safeguards could be considered during an appropriate monitoring program (clause 9 of ISO 45001) in the organization to ensure that the safeguards are not bypassed.

The actual version of the proposed tool could contribute to the Plan-Do-Check-Act (PDCA) procedure that the OHS management system (ISO 45001, 2018) is founded on to achieve continuous improvement. The probability of bypassing could be estimated in the planning process of the organization. Afterwards, during the "Plan" step, the safeguards could be put into order from the most to the least probable for being bypassed. Then, the existing incentives to bypass could be ranked by their effect level, as described in Table 5.3. That hierarchy could guide the actions necessary to eliminate or reduce the incentives to bypass. The "Do" step could aim at implementing the preventive measures against bypassing in the priority order defined from the hierarchy that was previously mentioned. For instance, taking scenario X (Table 5.10) as an example, the action plan would be to take care of the safety light beam before the pressure-sensitive mat since the probability of bypassing is higher for the previous one. Afterwards, the incentives with the maximum level ("++") of effect would be taken care of before those with a lower effect ("+" then "0"). If many incentives were to have the same level of effect, we suggest the OHS practitioner start with the incentives to which collective preventive measures are associated. Therefore, he or she should use incentives related to the equipment first (i.e. the "Machinery or safeguarding category") since according to the risk management process described in ISO 12100 (2010), collective measures such as: inherently safe design measures, guards, and protective devices are intended to mitigate the risk of accidents as much as possible compared to individual measures such as: personal protective equipment, training and work procedures. If having two incentives related to the same kind of protective measure were to happen, the priority between them could be applied by consensus according to the OHS practitioner and the worker representative's judgment. Haghighi, Chinniah, et al. (2019) proposed a list of incentives available for each of the five categories of incentives. Once the adequate preventive measures are applied at the "Do" step to tackle the existing incentives, the OHS practitioner should verify with the worker representative or the end-user whether the preventive measure fulfilled its mitigation function as desired (the “Check” step). If further actions are required to improve the applied preventive measures, the “Act” step comes along in order to refine and reduce the probability of bypassing. After implementing all of the necessary preventive measures, the proposed tool should be used again to update the bypassing situation in the assessed workplace. That said, the tool should show a reduced probability of bypassing.

The proposed bypassing-related assessment tool is meant for the machinery use phase. However, the tools from previous research studies were meant for the design, manufacturing and procurement phases. Therefore, it is impossible to evaluate and compare whether the performance of applying the new tool is better than previous ones. Nevertheless, as stated in the introduction, the research was conducted to propose a tool that will cast a wider net than the existing tools (DGUV, 2013; IFA, 2011; Suvapro, 2007) aimed at preventing bypassing of safeguards on industrial machinery. The proposed tool covers a detailed interdisciplinary list of incentives to bypass that, contrary to existing tools, not only focuses on machinery-related incentives to bypass. The proposed tool is able to assess the probability of bypassing based on four other categories of incentives: 1) ergonomics, 2) productivity, 3) behavior, and 4) corporate climate. The proposed tool is also flexible for adding activities and incentives. The use of a detailed list of incentives to bypass as one of the main parameters to estimate the probability of bypassing makes it possible to consider all actual incentives in the enterprise, as well as to identify potential incentives. By using this tool, enterprises can discover which incentive category they need improvement for in order to prevent bypassing. Also, they could detect their weaknesses regarding the occurrence of bypassing in the workplace.

Given that the references available related to the probability estimation of bypassing were limited, the studies related to the development of the risk estimation tools (Azadeh-Fard et al., 2015; Burlet-Vienney et al., 2015; Jocelyn et al., 2016; Moatari-Kazerouni et al., 2015) have also been reviewed to construct our proposed tool as an original holistic assessment tool for the probability of bypassing. The proposed tool allows the bypassing probability to be estimated. Even though probability is quantitative, the results of the proposed assessment tool, like other risk estimation tools, will be subjective, since the answer to the question (How is the bypassing situation?) and the level of “the effect of incentives to bypass” is based on the OHS practitioners’ judgment and their evaluation, despite a careful definition given to each level in order to minimize that subjectivity. Also, despite the number of levels chosen to describe each parameter based on (Chinniah et al., 2011; Gauthier et al., 2012). Indeed, three levels help minimize the subjectivity and produce more reliable results. With an aim to minimize subjectivity, the tool must be applied by experienced OHS practitioners. OHS practitioners need to be familiar with the machines in order to guarantee adequate awareness of the work environment as well as the machines during the assessment. Having qualified OHS practitioners is important since Hietikko, Malm, and Alanen (2011) revealed that the background and the position of the participants who assess the risk and their knowledge related to the risk estimation have a significant impact on the quality of the risk analysis.

The proposed tool includes sufficient levels of bypassing probability, four levels ranging from low to high as the result of estimation. This is consistent with the construction rules for risk estimation tools as stated by Chinniah et al. (2011) and Gauthier et al. (2012) in order to generate more precise results that do not overestimate the probability of bypassing. The four probability levels of bypassing could guide OHS practitioners throughout the prioritization of prevention or protective measures against bypassing and to take care of that issue in their companies. In addition, this prioritization could help decision makers in organizations with limited resources for OHS such as budget limitations, time limitations and more.

After prioritizing, OHS practitioners could take into account the effect levels of incentives (i.e. three levels including no effect, slight effect and significant effect) to prioritize corrective or preventive actions to tackle the incentives, especially when the probability level of bypassing is identical for different scenarios (e.g. there is more than one scenario with a "high" level). Furthermore, the identification of incentives while applying the tool could help the OHS researchers and practitioners build a part of their accident-related cause tree analysis whenever that accident involves bypassing. In that case, the incentives to bypass could be one of the contributory causes of the accident occurrence. Moreover, the application of the tool can contribute to task observation and analysis in the ergonomic assessment method, aiming at preventing bypassing of safeguards on machinery. Since one of the main categories of the incentives is dedicated to ergonomics in the proposed tool, ergonomic factors that make a task difficult tend to be incentives to bypass. Therefore, it might be helpful to identify ergonomic incentives related to bypassing during observation and task analysis in order to reduce the probability of bypassing.

5.5.3 Impact and further research

The OHS practitioners in enterprises dealing with machinery can apply the proposed tool to assess the probability of bypassing safeguards based on the identified incentives. The results of the assessment could guide the reduction of probability in order to increase a worker's safety. In addition, the output of this tool could be a suitable input for defining corrective and preventive actions. Such results of the proposed tool might be useful as a guide for OHS practitioners, inspectors as well as for OHS organizations such as CNESST[20], OSHA[21] and HSE to define action plans to mitigate or eliminate the incentives to bypass and to control the probability of bypassing in work areas.

In this research, the accident reports had been suitable cases that illustrated the usability of the proposed tool. To move our research forward, we plan to apply the tool in enterprises. The enterprise could select the existing incentives for different activities in their workplace from the tool. Afterwards, they could prioritize improvement actions needed according to the probability levels of bypassing. Indeed, the validation of the proposed tool has been planned in two steps. The first step was about testing it with five scenarios explained in this paper. Another step would be to apply it to an actual company in the future.

This paper may serve as a base for future studies with new ideas to further develop the proposed tool. For instance, future research could aim at applying the proposed tool to an organization with an OHS practitioner. The probability of bypassing could be assessed on real machinery. Furthermore, preventive solutions from Haghighi, Chinniah, et al. (2019) could be recommended according to the bypassing probability hierarchy from the proposed tool.

While 72 possible incentives to bypass in five main categories need to be investigated in order to identify and estimate the existing incentives to bypass in the company for each activity on machinery, the assessment process may be time consuming for the OHS practitioner. This point could be analyzed during the second step of validating the proposed tool where it could be applied to a case study in a real company and the OHS practitioners' point of view will be explored.

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[20] "*Commission des normes, de l'équité, de la santé et de la sécurité du travail*" is an organization in Québec that sets rules for working conditions to ensure a safe working area and for equal pay for equal work (reference: http://montrealgazette.com/news/local-news/csst-and-others-to-merge-and-form-cnesst)

[21] The Occupational Safety and Health Administration sets and enforces standards to ensure safe and healthy working conditions.

The proposed tool could also be applied by focusing on machines of a specific type and in a specific plant. It could also be applied to various industrial sectors with different machinery and safeguards to ensure that the tool is practical in different situations. As Moatari-Kazerouni et al. (2015) suggested, generalizing the application of a proposed machine risk estimation tool to many real case studies allows for its practicality to be validated.

5.6 Conclusions

Many occupational accidents occur due to bypassing guards and protective devices on machinery. Organizations must identify the incentives to bypass and ways to prevent bypassing, which is a prevalent problem in industry. This paper deals with a current issue and proposes a tool to estimate the probability of bypassing, which can be applicable in a wide spectrum of industries such as the manufacturing sector. The intent of the proposed tool is to assess the existing incentives to bypass and to determine the probability level of bypassing in order to prioritize the needs for improvement. The proposed tool is designed on the basis of the structure and logic adapted from IFA's incentive-to-bypass assessment matrix. When using the proposed tool, at step 1, the OHS practitioner identifies the machinery-related activities and their operation modes. At step 2, he or she lists the existing machinery safeguards. Step 3 investigates the existence of bypassing through the OHS practitioner's three possible answer to the following question: "How is bypassing situation?". That question is an influencing parameter. At step 4, the OHS practitioner selects the existing incentives to bypass, as another influencing parameter, within a wide scope of incentives of diverse categories: ergonomics, productivity, behavior, machine or safeguarding and corporate climate based on Haghighi, Chinniah, et al. (2019). He or she assigns an effect level among the three available to every selected incentive. Finally, at step 5, the tool automatically estimates the probability of bypassing using the influencing parameters and their corresponding levels. Four levels ranging from low to high are considered for the probability of bypassing in order to attain sufficiently precise results.

Five scenarios were selected to show the usefulness of the tool in regards to industrial situations. They were accident reports in which bypassing was one of the contributing factors in accidents. The tool was tested with those scenarios and the results show that the levels of probability were moderate to high because bypassing was present in all accident reports and incentives actually or potentially exist. The most common incentive in all scenarios was related to the inadequacy of existing safety procedures.

The tool will be further validated in future research by applying it to an actual company and on real machinery.

The OHS practitioners in the companies could now look for and identify the existing incentives to bypass among an interdisciplinary list of possible incentives involving various aspects in the work environment rather than attributing the bypassing of safeguards to operators' failure.

The results of the proposed tool can be used directly in industry, and could serve as a guide for OHS practitioners in companies and OHS organizations to eventually prioritize their preventive actions in such a way that the incentives to bypass could be reduced or eliminated. Subsequently, bypassing-related occupational accidents could be prevented. However, the tool needs to be used by a competent OHS practitioner to ensure an accurate probability estimation of the bypassing.

An OHS management system (e.g. ISO 45001) has different elements, such as commitment management, policy and procedures, employee participation, the competence and awareness of workers, training, risk assessment, procurement, auditing and more. Since the incentives identified in the five tested scenarios show that deficient OHS management causes the occurrence of bypassing in enterprises, the issue of bypassing should be integrated in those elements to create more attention and to define improvement actions for eliminating nonconformities.

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CHAPTER 6 ARTICLE 3: TESTING AND IMPROVING AN ISO 14119-INSPIRED TOOL TO PREVENT BYPASSING SAFEGUARDS ON INDUSTRIAL MACHINES

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Abstract

Various safety-related standards associated with the machinery design phase, such as ISO 14119:2013, emphasize the appropriate design and selection of protective devices to prevent bypassing. Despite such standards, bypassing safeguards is a common issue at the machinery use phase. ISO 12100:2010 indicates, “experience has shown that even well-designed safeguarding can fail or be violated”. This unsafe practice can cause serious injuries or fatalities. This paper presents an improved version of a bypassing-related assessment tool initially inspired by ISO 14119. The improvement results from testing its performance through industrial case studies to explore how the tool works in reality. Five occupational health and safety (OHS) practitioners apply this tool in four plants in Quebec to 18 machines and 37 activities. Afterwards, the OHS practitioners provide feedback using a questionnaire. The findings reveal that the tool is appropriate for the machine usage phase to prevent bypassing with an overall 82% satisfaction score. The probability levels of bypassing given by the tool enable a safety improvement prioritization method for the machines and safeguards. The tool was improved, redefining some incentives to bypass and its layout. The findings explain how practitioners could influence decision-making to minimize incentives to bypass and the probability of bypassing to prevent accidents.

Keywords: occupational health and safety; defeating safeguards; assessment tool; probability of bypassing; preventive measures; accident prevention; continuous improvement; safe workplace

6.1 Introduction

In manufacturing systems, operations management studies pay more attention to operational issues than to occupational health and safety (OHS) issues (Pagell, Johnston, Veltri, Klassen, & Biehl, 2014). Therefore, to run a more productive manufacturing system, operational and maintenance workers often take shortcuts regarding safety when they are under pressure to carry out their tasks (Lo, Pagell, Fan, Wiengarten, & Yeung, 2014). Bypassing safeguards, i.e., guards and protective devices on machinery, is an example of a shortcut taken that impacts safety. Bypassing refers to the action that workers take to disable protective devices or remove guards in order to, for instance, follow production plans or to compensate for poor design that did not take into account the actual tasks and the safety of the workers who perform the tasks.

Operations management in manufacturing sectors usually ignores OHS issues in the company to increase the firm's profitability and productivity. The company may then endure damage from occupational accidents or illnesses. Some of the damage may include the interruption of operations (Fernández-Muñiz, Montes-Peón, & Vázquez-Ordás, 2009), reputational damage (Smallman & John, 2001), employee compensation, hospitalization and medical costs (Loeppke et al., 2007), absenteeism, labor turnover and new worker training costs (Hesapro, 2013). Moreover, beyond the monetary costs and operational damage that could occur, irremediable damage may also happen to a family if a worker's death occurs. Therefore, managers of manufacturing systems found that serious attention to safety is necessary to improve productivity (Dabbagh & Yousefi, 2019). They also need to perform "decision-making approaches and safety management systems" to avoid extreme costs (e.g., "damage to equipment and products") due to the accidents (Dabbagh & Yousefi, 2019).

A HVBG (the German Federation of Institutions for Statutory Accident Insurance and Prevention, which is called Hauptverband der gewerblichen Berufsgenossenschaften (HVBG)) report presented the results of a study in the field of bypassing of protective devices on metalworking machines in Germany. It revealed that approximately 37% of protective devices were permanently or temporarily bypassed (Apfeld et al., 2006). Apfeld (2010) stated that more than 10,000 accidents and eight fatalities occurred as a result of the manipulation of protective devices in Germany in 2008. Suva (a company in Switzerland; its field of activities are prevention, insurance, rehabilitation, and the safety of working areas in organizations) carried out a survey of 300 companies in Switzerland and found that in half of those companies, protective devices were defeated (Zimmermann, 2007). "The defeating of interlocking devices can increase significantly the risk of harm and so far as practicable protective measures shall be taken to minimize the effect of such foreseeable misuse" (ISO 14119, 2013). Therefore, Annex H of the ISO 14119:2013 standard proposed a method that "supports the machine designer in identifying possible incentives for defeating the interlocking devices". Despite having that method to contribute to the safe design of automatic machines, bypassing still occurs on machinery at the use phase. Moreover, bypassing involves all kinds of safeguards as shown in Section 6.1.1, and consequently, not only interlocking devices. Thus, preventing the bypassing of safeguards is a significant issue in the field of machinery safety that needs to be taken into account for the use phase: during operations and other activities, to ensure that a safe workplace is provided for workers. To tackle this issue, Haghighi, Jocelyn, and Chinniah (2019a) proposed a holistic assessment tool inspired by ISO 14119 (Appendix F) to prevent the bypassing of safeguards in general at the use phase of machines. Their tool qualitatively estimates the probability of bypassing by identifying the possible incentives that do exist. However, the feasibility of their tool has not yet been tested by end-users on real machinery for different activities. Accordingly, this paper first carries out that feasibility study by applying their assessment tool to case studies. The case studies are based on estimating the probability of bypassing safeguards on 18 machines throughout 37 activities in four plants in the province of Quebec, Canada. Second, based on the end-users' comments gathered throughout that feasibility study, this paper presents an improved version of Haghighi, Jocelyn, et al. (2019a)'s tool.

The remainder of this paper contains four sections. After presenting the importance of the bypassing issue in industry, as well as the scope of the paper (Sections 6.1.1 and 6.1.2), Section 6.2 introduces the method of research. Section 6.3 presents the results and Section 6.4 discusses them. Section 6.5 concludes the paper.

6.1.1 A Review of the Importance of the Bypassing Issue in Industry

Operations management is a multidisciplinary area that incorporates process management, operations, and equipment maintenance management to support a company's strategic goals, as well as to create necessary improvements for higher profitability within an organization. OHS issues are taken into account as a crucial element in operations management for moving toward business excellence. Fan, Lo, Ching, and Kan (2014) stated that publications related to the integration of operational issues and OHS issues have grown enormously in the past six years. They identified four paramount research areas of OHS issues in operations management including (i) "safety climate", (ii) integration of management systems, (iii) "voluntary OHS systems", and (iv) "sustainable operations". In highly reliable organizations, a worker's safety is an operational priority. Thus, the workers trust management to carry out their tasks in a safe climate (Colquitt, LePine, Zapata, & Wild, 2011). The workers focus on pursuing organizational goals, including operational and safety goals, when their basic safety needs are met in the workplace (Das, Pagell, Behm, & Veltri, 2008). Amponsah-Tawiah and Mensah (2016) found a significant relationship between OHS and organizational commitment. They concluded that employees who feel safe and healthy during their tasks are more committed to their organizations. In addition, Johnston, Pagell, Veltri, and Klassen (2020) found four “values-in-action” that must be present in the plants and combine with each other in order to involve managers and workers in supporting safe production. These “values-in-action” are: “a commitment to safety, discipline, prevention and participation”. High-reliability organizations are able to prevent quality failures, delivery delays and accidents (Lo et al., 2014). Therefore, the management of such reliable organizations does not overlook the contributing causes of occupational accidents in order to prevent incidents in the working environment. Published information related to the occupational accidents identified bypassing safeguards as one of the contributing causes (Backström & Döös, 2000; Charpentier, 2005; Charpentier & Sghaier, 2012; Chinniah, 2009, 2015a; Chinniah & Bourbonniere, 2006; Chinniah et al., 2007; Dźwiarek, 2004; Gardner et al., 1999; Hopkinson & Lekka, 2013; Huelke et al., 2006; Järvinen & Karwowski, 1993; KANbrief, 2003; Mattila et al., 1995; D. L. Parker et al., 2009; Pratt & Hard, 1998; Samant et al., 2006; Shaw, 2010; Vautrin & Dei-Svaldi, 1989). Management needs to consider this unsafe act in work areas to prevent bypassing-related accidents, which is a significant factor in maintaining the link between safety and operations management in order to achieve organizational excellence.

Some standards and regulations related to the OHS and machinery design requires machine designers to consider the defeating issue during the design and selection of safeguards so that guards and protective devices (CSAZ432, 2016; Le parlement européen, 2009), interlocking devices associated with guards (ISO 14119, 2013), the electro-sensitive protective equipment (ISO 13855, 2010), and the protective effect of a two-hand control device (ISO 13851, 2002) would be difficult to bypass. The International Standard ISO 12100 (2010) states that the risk estimation process should consider the defeating possibility of safety measures. Despite these requirements in the design phase, ISO 12100 (2010) pointed out that “even well-designed safeguarding can fail or be violated”. Furthermore, ISO 13851 (2002) noted that the total protection of a two-hand control from “defeat” is not possible. In addition, Apfeld et al. (2006) revealed that 50% of machines that were bypassed had a CE (European Conformity) mark. Therefore, the procurement of a CE-marked machine does not solely guarantee that bypassing will not occur (IFA, 2011).

In addition, the www.stop-defeating.org website released information online for machine designers, machine manufacturers, and machine users to prevent manipulation. Caputo et al. (2013) presented a systematic method based on the Analytic Hierarchy Process (AHP) approach for selecting suitable safety devices on machinery. “Tampering avoidance” was one of 15 factors that were regarded for pair-wise comparisons to select suitable safety measures for industrial machinery. Racz, Breaz, and Cioca (2019) also proposed “tampering avoidance” as one of the criteria for the evaluation of safety devices for Computer Numerical Control (CNC) machine tools using the AHP method. KANbrief (2003) revealed that technical measures such as user-oriented and ergonomic concepts should be taken into account in the design phase to avoid defeating.

Chinniah et al. (2007) stated that various factors, in combination with the bypassing of safety devices that may be bypassed for different reasons, potentially generate a hazardous workplace: (i) companies import machines from countries that have different regulations of safety, (ii) companies may purchase and use machines that have improper safeguarding, and (iii) engineers, with insufficient knowledge related to the “risk assessment and machine safeguarding”, might upgrade or customize the machines.

Safe industrial machinery is not enough to mitigate machine-related accidents. Machine users operate the machines with residual risks in unsuitable ways, such as bypassing protective devices if they are not familiar with machine safety. On the other hand, if designers overlook users’ points of view during the design phase, users might remove the guards or disable the interlock switches because, for instance, the machine may be inappropriate to use, the machine may be difficult to access, or the machine may frequently stop (Tochio et al., 2010).

Apfeld et al. (2006), through an investigation of 202 machines in metalworking in Germany, found that the majority of machinery that was defeated included: a machining centre (25.2%), CNC lathe machine (16.3%), press (13.4%), CNC milling machine (7.4%) and conventional milling machine (5.4%). In addition, the manipulation mainly took place at movable guards with a position switch or locking (54%), and mechanical, not movable guards (35%). These authors also concluded that the number of manipulations in automatic mode is surprisingly high. Moreover, manipulation most frequently happened during the following activities outside of the automatic mode: setup and adjustment (19.7%), programming, program test and test run (10.7%), and modifying, setting and changing the tool (5.3%). The operating modes in which manipulation took place were occupied in the first place by special operating modes, such as troubleshooting, setup, modification, cleaning, and maintenance. Apfeld (2010) and Lüken et al. (2006) overviewed the above-mentioned study. Apfeld (2010) revealed that defeating was most frequently detected in the following operation modes: troubleshooting machinery, setting up, troubleshooting organizational work, tool exchange, cleaning, maintenance, and adjustment. The neutralization of protective devices often occurred in the set-up, troubleshooting, reconstruction and automation modes (Lüken et al., 2006). Hopkinson and Lekka (2013) identified that defeating interlocks of CNC machines is more prevalent for activities such as drilling, swarf removal, setting, proving, deburring, finishing and polishing, machining inside pipes, and removing or replacing a collet.

Bypassing safeguards is identified as a prevalent problem in industry. Therefore, researchers are motivated to pay more attention to identifying existing incentives behind bypassing. Diverse reasons for defeating were found—the most frequent included (i) tasks such as installation, repair, maintenance are impossible without defeating, (ii) lack of visibility, (iii) poor reliability of guards and protective devices, (iv) disturbance of work process and production, (v) enhancing productivity, and (vi) lack of management commitment (Adams, 2001; Apfeld et al., 2006; Backström & Döös, 2000; Charpentier & Sghaier, 2012; Chinniah, 2009, 2015a, 2015b; Freedman, 2004; Hopkinson & Lekka, 2013; IFA, 2011; ISO 12100, 2010; Johnson, 1999; KANbrief, 2003; Lüken et al., 2006; Mattila et al., 1995; McConnell, 2004; Neudörfer, 2012; Roudebush, 2005; Schuster, 2012; Sherrard, 2007; Zimmermann, 2007). Haghighi, Chinniah, et al. (2019) carried out a comprehensive review of bypassing of safeguards and extracted 72 possible incentives to bypass. They classified those incentives to bypass into five main categories: (i) ergonomics, (ii) productivity, (iii) machine or safeguarding, (iv) behavior, and (v) corporate climate.

After exploring the incentives to bypass, they presented, based on a literature review, 82 preventive recommendations to reduce or eliminate the incentives for defeating in many different industries. The most frequent improvement proposals suggested by the literature are (i) improving the design of machines and safeguards, (ii) considering employees' points of view for machine procurement, (iii) providing adequate supervision, (iv) training employees to understand the necessity of using safety measures, and (v) periodic inspections performed by managers and supervisors to ensure that interlocks were enabled (Adams, 2001; Apfeld et al., 2006; Dźwiarek, 2004; Freedman, 2004; Hopkinson & Lekka, 2013; Järvinen & Karwowski, 1993; Johnson, 1999; Lüken et al., 2006; McConnell, 2004; Sherrard, 2007). Dźwiarek (2019) recently presented measures and technical solutions to limit the circumvention of interlocking devices related to the guards.

As such, three studies have proposed some tools to promote the use of safeguards including (i) ISO 14119 (2013), a machine safety design standard, published an informative guide assessing the motivation to defeat interlocking devices, which referred to an assessment matrix designed by IFA (2011). The IFA assessment matrix was developed for the design phase for identifying the benefits that may exist without protective devices and evaluating the incentive to bypass (ITB). (ii) DGUV (2013) designed a checklist for procuring a machine. That checklist contains complementary information to ensure that the machine would be purchased with the minimum motivation to bypass protective devices, and (iii) Suvapro (2007) presented a general checklist to control the hazards of manipulation. This control list enables the measures to be defined and then follows up with those measures to stop the circumvention of protective devices. In addition, Haghighi, Chinniah, et al. (2019) accomplished an extensive review of preventive solutions. In this study, the influential factors that prevent defeating are classified into technical, organizational, and individual categories, which could be considered in the design, machine manufacturing, and usage phases. Moreover, Haghighi, Jocelyn, et al. (2019a) have developed a holistic assessment tool to estimate the probability of bypassing in the machine usage phase based on the construction rules of the OHS risk estimation tools recommended by Chinniah et al. (2018); Chinniah et al. (2011); Gauthier et al. (2012). On the one hand, the holistic tool enables the OHS practitioners in enterprises to identify the existing incentives to bypass in their work environment. On the other hand, this tool integrates the operational issues and safety issues in the context of bypassing with regards to a complete list of activities during the assessment. The study only tested the tool with five accident reports, which were the bypassing scenarios, to ensure its usability. However, the proposed tool has not been tested with real machinery in real companies that are machine end-users.

6.1.2 The Scope of the Paper

According to the literature review mentioned above, there are shortcomings during the machine design and machine manufacturing phases. Therefore, (i) difficulties persist, even after the design and building phases, (ii) various possible incentives to bypass exist in the work environment, and subsequently, (iii) the bypassing-related accidents show that machine users need a bypassing-related tool that could help them prevent bypassing in their companies. Through real case studies in industry, this paper aims to test the bypassing-related assessment tool proposed by Haghighi, Jocelyn, et al. (2019a) initially inspired by ISO 14119. Actual OHS practitioners in the companies will apply the tool to various real machinery in order to test its performance in a practical setting. Consequently, this paper presents an improved version of that bypassing-related assessment tool through OHS practitioners' feedback.

6.2 Materials and Methods

To meet the objective of this paper, specific criteria were listed and formulated into a questionnaire (Appendix G). Then, the research process continued with the application of the holistic assessment tool using case study research. Case study research is problem-based research to provide an empirical investigation and an in-depth analysis of the cases (Hancock & Algozzine, 2016). In addition, Hancock and Algozzine (2016) have stated that this kind of systematic research process provides an accurate step-by-step analysis of the case.

This study was conducted as a part of a research project. Its protocol was approved on January 28th, 2019 by Polytechnique Montréal's Ethics committee for research projects involving human subjects (project reference number: CÉR-1819-45). The informed consent form was prepared to clarify the companies' participation. The research team and the companies that agreed to participate in this research signed the form. All subjects gave their informed consent for inclusion before they participated in the study. Before applying the assessment tool at the companies, all required documents, including the assessment tool, the informed consent form, and the questionnaire, were prepared in French, the official language in the province of Quebec, Canada. The research team invited the companies to ask them to explain any words or information that was not clear, as well as any questions that they had during the application of the assessment tool or when filling out the questionnaire. In the following section, we provide an outline of the research method.

6.2.1 Selection and Recruitment of the Companies

No exact and accurate guides exist to help choose the appropriate number of cases in a case study methodology (Perry, 1998). Eisenhardt (1989) pointed out that between four and ten cases are usually sufficient. Generating theory with enough complexity would be difficult based on fewer than four cases. Handling the volume and the complexity of the data would be difficult with more than ten cases. Therefore, four companies in the manufacturing sector in the province of Quebec, Canada were selected and recruited. A total of five OHS practitioners in those companies agreed to take part in the study and applied the tool to 18 existing machines in their plants. Having a familiarity with the bypassing issue was one of the selection criteria for the chosen companies. Moreover, the audience in this study were OHS practitioners and they needed to be able to apply the assessment tool; therefore, the other criteria for selection were a strong background in OHS with more than two years of experience in the field and an awareness of managing all types of industrial machinery risks. Table 6.1 summarizes the list of companies selected. Small-, medium- and large-sized companies agreed to take part in the study (Table 6.1). According to the categorization of enterprises based on the employment size, small, medium-sized and large enterprises are, respectively, enterprises with 1 to 99 employees, 100 to 499 employees and 500 employees or more (Leung, Rispoli, & Chan, 2012).

Table 6.1 General information about the four companies for the application of the tool

Company	**Type of Production /Services**	**Number of OHS Practitioners Who Were Involved**	**Number of Employees**	**OHS Practitioner's Years of Experience (years)**	**Number of Machines Selected**	**Number of Activities Performed for Testing**
A	Equipment design and manufacturing	2	625	5 and 20 years	5	7
B	Iron and steel	1	125	16 years	4	7
C	Horticulture and agriculture	1	700	10 years	5	15
D	Pulp and paper	1	60	12 years	4	8
Total		5			18	37

6.2.2 Organization of Visits and Meetings with the Team of OHS Practitioners

The research team prepared the required files and documents for the companies. The package included the informed consent form, the assessment tool available as an Excel spreadsheet and the questionnaire. The research team visited the companies during the workers' shifts. During their visits, they observed the existing machines and safeguards in the companies in order to find out general information about the company that could be helpful in the data analysis process. Afterwards, consultation was held with the OHS practitioners to describe how the assessment tool should be used and the questionnaire to be completed. The research team also mentioned that the team of OHS practitioners could consult workers when applying the assessment tool.

6.2.3 Information Collection

The team of OHS practitioners in each company investigated the bypassing issue in their plants. They also carefully investigated the work environment, the condition of the machinery and safeguards. During the investigation, a member of the research team guided the OHS practitioners on the implementation of the assessment tool. These practitioners selected some of the existing machines with various safeguards. They applied the tool (Appendix F) in the Excel spreadsheet to the machines selected that were bypassed in their plants. They used the tool following the boxed step-by-step procedure (Table 6.2). Then, they returned the complete information to the research team. The entire information collection process lasted about two months.

6.2.4 Data Analysis

The research team imported the information gathered from the companies in an Excel worksheet to facilitate a detailed analysis. In addition, the team interpreted the results and suggested preventive measures to eliminate or reduce bypassing safeguards based on the preventive recommendations provided in Haghighi, Chinniah, et al. (2019). The observations during the visits and information returned by OHS practitioners from the companies were taken into account in proposing possible improvement actions. Section 6.4 discusses the results in detail.

6.2.5 The Final Test Step

The research team asked the OHS practitioners to return their feedback in the questionnaire (Appendix G) prepared based on the objectives of this paper, as Bell (2014) recommended. The companies filled out the questionnaire after applying the assessment tool to the various machines and activities. They sent their feedback to the research team as assigned. The latter imported the feedback received from each company into an Excel spreadsheet. The team analyzed the limitations of the tool given by the feedback and other comments through the returned questionnaires. The appropriateness of the assessment tool was evaluated by considering the following phases: 1) while using the tool, and 2) the results of the tool. The team considered the appropriateness of the assessment tool, the limitations identified and the OHS practitioners' comments to improve the tool.

Table 6.2 The instructions for applying the bypassing-related assessment tool

Instructions for Applying the Bypassing-Related Assessment Tool	
This tool has been designed for OHS practitioners. It helps them identify existing incentives to bypass and estimate the probability of bypassing	
1-	Write the name of the machine.
2-	List the activities implemented on the machine in order to have as precise of an assessment as possible (OHS practitioners can adapt the activity list with the participation of operators).

Table 6.2 The instructions for applying the bypassing-related assessment tool (continued)

3-	The modes of operation can be selected with an asterisk as manual, automatic or something else for each activity (if there are other modes of operation, you can add a new column).	
4-	The existing bypassed safeguards for each activity would be written (the OHS practitioner can assign more than one safeguard to an activity and write other safeguards in the next rows).	
5-	Answer the "How is the bypassing situation?" question by selecting one of the following entries for each safeguard:	
	A	The safeguard is bypassed and the OHS practitioner in the enterprise notices actual incentives to take corrective measure.
	B	The safeguard is not bypassed, but the OHS practitioner in the enterprise observes some potential incentives. That may cause bypassing in the future.
	C	There are no incentives to bypass.
6-	Identify the existing incentives to bypass (potential or actual) among the possible incentives classified in the tool per the five categories that are available: 1) ergonomics, 2) productivity, 3) behavior, 4) machine or safeguarding, and 5) corporate climate. Three levels are considered to estimate the impact of the incentives on the probability of bypassing. Select one of the following effect levels based on your judgment:	
	0	No effect due to the nonexistence of an incentive.
	+	Slight effect of an incentive on the probability of bypassing.
	++	Significant effect of an incentive on the probability of bypassing.
7-	The probability of bypassing is automatically calculated by Excel functions. Four levels are considered for the probability of bypassing to attain adequate results for prioritization.	
	High	The corresponding answer to the question from step 5 is A and half or more than half of the incentives identified for the activity have a significant effect (++) on the probability of bypassing.
	Significant	The corresponding answer to the question from step 5 is A and fewer than half of the incentives identified for the activity have a significant effect (++) on the probability of bypassing.
	Moderate	The corresponding answer to the question from step 5 is B and there is at least one incentive identified for the activity that has a slight effect (+) or significant effect (++) on the probability of bypassing.
	Low	The corresponding answer to the question from step 5 is C and there is no reasonably foreseeable incentive for the activity (0).

6.3 Results

Appendix H presents the results obtained by directly applying the tool to 37 activities performed on 18 machines in the four companies. For every safeguard, the table in Appendix H informs the operation mode in process during activity, as well as the identified incentives to bypass. The table also communicates the probability level of bypassing given by the tool and associated with the safeguard under investigation**.** All of this information is analyzed in Section 6.4.

Table 6.3 shows general information extracted from the returned questionnaires related to its "yes" or "no" questions. Considering the average percentage of "yes" every company answered, there was a high level (82%) of satisfaction with the tool throughout its application to 18 machines and 37 activities. The two dashes in column B represent unclear answers from the company. Consequently, they were considered as outlier data. Accordingly, they were excluded from the calculation.

Table 6.3 General information extracted from returned questionnaires

Questions		**Companies**			
		A	**B**	**C**	**D**
While using the tool	1. Is the list of incentives in the tool satisfying?	No	Yes	Yes	Yes
	2. Is the tool easy to use (user-friendly)?	Yes	No	Yes	Yes
	3. Is the tool useful to identify the incentives to bypass in the company?	No	Yes	Yes	Yes
The results of the tool	1. Is the tool appropriate to estimate the probability of bypassing in the company?	Yes	-	Yes	No
	2. Are the probability levels of bypassing accurate based on the work environment of the company?	Yes	Yes	Yes	Yes
	3. Is the tool useful to prevent bypassing?	Yes	-	Yes	Yes

Table 6.4 presents the positive and negative feedback collected from the companies.

Table 6.4 Pros and cons of the assessment tool collected from the companies

Phase	**Pros**	**Cons**
While using the tool	- The list of incentives in the tool is satisfying. It is complete with a lot of possible incentives. - The tool is easy to use (user-friendly). In addition, the drop-down list provided for selecting different options makes the tool easy to use. - The tool is useful to identify the incentives to bypass in the company because it directly targets the various incentives to bypass. It could also be useful if a new task or new machinery were added.	- Some incentives (I42 and I43) sound similar. More explanation is required for understanding them better and having objective evaluation. - I36 may deserve to be split into more than one incentive because management can be tolerant of the situation without encouraging. Also, an antibypassing policy could exist but in some management levels would not be applied. - Too many clicks are required by the mouse to check the cells rather than simply using the keyboard. It makes the form more tedious to be completed. - If the incentives are exhaustive and detailed, the tool could give a clear idea for defining the improvement points to prevent bypassing.

Table 6.4 Pros and cons of the assessment tool collected from the companies (continued)

Phase	Pros	Cons
The results of the tool	- The tool is appropriate for estimating the probability of bypassing in the company because the probability level of bypassing estimated by the tool was "High" for the bypassing cases occurred in the company. - The probability levels of bypassing are accurate based on the work environment of the company. - The tool is useful to prevent bypassing because it targets the existing incentives that should be improved. Therefore, the company will focus on those incentives in order to prevent bypassing. It will help reduce the risks. It can also be useful if the task has not been analyzed.	- No companies have negative feedback.

6.4 Discussion

6.4.1 How the Results Improve the Tool

Based on the feedback in Table 6.4, the following are some examples of improvements that were brought to the tool:

- The incentive with the code "I42" was revised in order to be distinguished from "I43" (See Appendix I). Since each of the manners, either ordering, tolerating, encouraging or ignoring the circumvention, is a lack of management commitment according to the authors' points of view, this incentive (I36) would not be split, but it was revised for clarification (See Appendix I). In addition, the authors have provided exhaustive and detailed expressions for each incentive that will guide users of the tool to better understand the incentives and make an objective evaluation. Thus, the Microsoft Excel file is comprised of three sheets: 1) instructions for applying the bypassing-related assessment tool (Table 6.2), 2) a detailed explanation of incentives, and 3) the assessment tool.

- To address the last point of the cons, the authors reverified the existing version of the assessment tool. Therefore, users are free to use either the mouse or the keyboard when marking the cells.

According to the findings, Annex H of ISO 14119 (2013), a safety-related standard at the machine design phase, suggested a method for machine designers. This method was created in reference to the assessment matrix designed by IFA (2011). It allowed machine designers to identify the motivation to defeat. The results can indicate that 1) the design of the machine is safe; 2) improvements are compulsory in the design of the machine; or 3) several “potential benefits of working without protective devices” are only identified. However, the results cannot determine whether bypassing would actually happen, because designers require information about other factors such as organization culture, stress in the workplace and more. Therefore, “The designer should check whether improved practice-orientated safeguards are possible” to make sure that defeating would be unessential. While the ISO 14119-inspired tool has been developed for the machine use phase, it allowed OHS practitioners in the companies to identify actual and even potential incentives to bypass. They could detect the flaws associated with the machine or safeguarding, the company culture, work conditions or individuals’ behavior, that motivated the workers to bypass the safeguards. In addition, they could figure out the bypassing cases that have actually occurred and also the potential situations of bypassing based on the probability levels of bypassing. The results also provide an opportunity for the machine users to identify the incentives to bypass related to the machine or safeguards when they operate the machine in their workplace. Therefore, they could communicate with manufacturers and machine designers to find suitable measures to overcoming bypassing. On the other hand, the machine designers could benefit from such knowledge while designing new machines. ISO 12100 recommends that feedback be provided from the user to the designer in order to continuously improve the safety of machinery. Consequently, the tested and improved bypassing-related assessment tool contributes to enabling that feedback. As KANbrief (2003) noted, designers are not the only ones responsible for making bypassing more difficult, and operators’ responsibilities should not be lessened. Therefore, the two above-mentioned tools (i.e., the ISO 14119-inspired tool and the tool suggested by ISO 14119 based on the IFA assessment matrix) could be complementary to evaluate incentives to bypass in both the design and usage phases.

According to OHS practitioners, some limitations exist that need to be taken into account when applying the assessment tool in order to achieve better results:

- First, company A is a company that designs and manufactures the equipment (shown in Table 6.1) for customers (i.e., the equipment is customized,) such as baggers and robot cells. That company also has a workshop including a lathe machine, grinding machine and others that are used in manufacturing. An interesting observation stems from the application of the assessment tool, which shows that the ISO 14119-inspired tool is more user-friendly, practical and adapted for manufacturing machines or factories that have production lines, rather than for machines that are manufactured. This fact is entirely consistent with the objective of the assessment tool, which is developed for the usage phase.
- Second, a multidisciplinary team, including the OHS practitioners, operators and even management, has a significant role in identifying the existing incentives and assessing their effect levels. The companies could achieve a more objective assessment this way, rather than only the OHS practitioners, who carry out the evaluation based on their own experience. This way, the results would be subjective because the OHS practitioners do not operate the machines. The participation of relevant mainstream operators provides a realistic evaluation. This fact is fully in line with the authors' intent. For this reason, during consultation with the companies before they applied the tool, the research team encouraged the OHS practitioners to benefit from operators' participation during the assessment. In addition, as Haghighi, Jocelyn, et al. (2019a) have stated, the subjectivity of the results could be minimized if the assessment tool was applied by experienced OHS practitioners who are familiar with the machines. As shown in Table 6.1, the OHS practitioners who have more than five years of experience applied the tool; this helps mitigate subjectivity. Furthermore, a lack of workers' involvement has been identified as one of the possible incentives (I53) in the bypassing-related assessment tool inspired by ISO 14119. Thus, workers' participation in the process for estimating the probability level of bypassing is as important as in the other OHS issues.
- Third, the maturity of the company with regards to OHS issues has a significant impact on having a realistic assessment. The company must be committed and willing to do the assessment in order to obtain more reliable results and honest feedback. Therefore, the research team considered voluntary participation in the process of company selection. The companies selected were eager to send back real information and feedback to the research team. In addition, the research team applied the assessment to more than one case study to decrease probable errors.

The other comments according to the OHS practitioners were:

1- The tool should be vertical and not horizontal. Writing the incentives vertically from bottom to top is not comfortable from an ergonomic point of view. The user may have bad posture during the application of the tool, and while entering the data. This comment was implemented in the new version of the tool (Figure 6.1).

2- The tool seems to be very useful. It challenges the methods used to make machines safe. The results show that the incentives can enormously change from one activity to another.

3- Sometimes, the incentives are not really related to the activity, thus, it was complicated in terms of how to assess the effect level of the incentive in that situation. According to (Haghighi, Jocelyn, et al., 2019a), the authors intended to develop a holistic assessment tool comprising of a wide scope of possible incentives to bypass (as mentioned in Section 6.1.1). Therefore, companies with various activities could identify the existing and relevant incentives among the 72 possible incentives classified into five main categories. It is reasonable that some incentives are not applicable from one company to another.

Machine:

				Activity							
Operation modes			Automatic								
			Manual								
			...								
Existing Safeguard											
How is the bypassing situation?											
The incentives to bypass	Ergonomics	I15	A safeguard reduces the visibility of the tools and activities such as working process, production, setting and so on.								
		⋮	...								
		I42	Safeguard is bypassed to facilitate the freedom of movement.								
		I43	Safeguard is bypassed to improve the flow of movement.								
		⋮	...								
		I71	Metabolic energy consumption will decrease by bypassing.								
	Productivity	I1	There is a lot of work to carry out.								
		⋮	...								
		I67	Profitability diminishes if the customer's order is not met.								
	Behavior	I5	Operators are inexperienced.								
		⋮	...								
		I72	Taking a risk is exciting for employees.								
	Machine or safeguarding	I16	Poor reliability of safeguards and their failures (e.g. false alarms, trips, and restarts) disturb the people and operations in the work area and stimulate a tendency to bypass.								
		⋮	...								
		I70	Clothing is caught or cuts happen because of the physical characteristics of a safeguard.								
	Corporate Climate	I12	Operators behave as though they are experienced.								
		⋮	...								
		I36	There is a lack of management commitment and managers either ordered, tolerated, encouraged or ignored circumvention.								
		⋮	...								
		I64	Current policies and procedures are inadequate.								
			The probability level of bypassing for the activity								

Figure 6.1 The improved version of the tool presented in Appendix F

The improved version is now available in Figure 6.1, which addresses the OHS practitioners' comments mentioned in Table 6.4.

6.4.2 Analyzing the Existing Incentives and the Probability Levels of Bypassing

A detailed analysis was carried out on the information provided in Appendix H. Eighteen machines and 37 activities were completely evaluated in four companies when applying the assessment tool. The companies applied the tool to some of the machines that exist in their plants. In addition, they identified the incentives to bypass safeguards for the main activities on each machine or the activities that they knew bypassing safeguards might allow when carrying out those activities. Therefore, the companies stated that the safeguards are in place and the workers cannot bypass the safety devices for all other activities. Moreover, in some cases, for tool exchange or cleaning, the workers would apply a lockout procedure. The workers would also carry out a risk analysis and follow a safe work procedure (e.g., safety tape, training, description of the method and other tools to ensure that the risk is under control). Thus, the answer to the question "How is the bypassing situation?" in the assessment tool is "C" if one only considers the machinery safeguards (since bypassing a work procedure is possible). The effect level of incentives would be "0" in this case, and subsequently, the probability of bypassing would be "Low" for all other activities. The results from the case studies as a sample show some instances of bypassing in plants in the province of Quebec, Canada. Those results illustrate that safeguards were bypassed when performing 20 out of 37 activities. Bypassing is more common in manual modes. Lathe machines (in companies A and D), conveyors (in company C) and Presses (in companies B and C) are more often bypassed. Different kinds of interlocking safety devices (e.g., interlocking removable guards, interlocking keys in the control panel), fixed guards and movable guards are the most prone to be defeated based on the results. Bypassing most frequently occurs during adjustment, processing or machining (e.g., wrapping the bags, pressing the parts and more), and troubleshooting activities. If we consider the list of activities classified by their type— in setting, operation, and maintenance— bypassing usually happens during operations (e.g., adjustment, machining, unjamming, inspection, and checking), then maintenance (e.g., cleaning, troubleshooting, and preventive maintenance) second.

An analysis was carried out on the incentives that cause the bypassing of safeguards on the machines studied. Table 6.5 illustrates the most frequent actual incentives to bypass (with slight or significant effects) in the companies. The incentives to bypass shown in Table 6.5 have been chosen based on the Pareto principle (80–20 rule). Twenty percent of the 72 incentives is equal to 14.4. Therefore, we considered the first 15 incentives from the list of all existing incentives in descending order of frequency in Appendix H. The companies believe that bypassing usually occurs due to the incentives related to productivity issues (Table 6.5). The majority of the most frequent incentives in the companies (I24, I19, I15, I17, I36, I44, I25, I8 and I 37) are identical to the most frequent incentives available in the literature (see Haghighi, Chinniah, et al. (2019)). Even though the four case studies do not allow for results to be generalized, the consistency in the literature shows a certain ability of the tool to be applied to overcome the bypassing issue related to machinery safeguards.

Table 6.5 The most frequent actual incentives (with slight or significant effects) in the companies by their category

NO.	Category [1]	The Actual Incentives to bypass (with Slight or Significant Effects)	N
1	E	Bypassing provides convenience and facilitates work (I24).	18

Table 6.5 The most frequent actual incentives (with slight or significant effects) in the companies by their category (continued)

NO.	Category [1]	The Actual Incentives to bypass (with Slight or Significant Effects)	N
2	P	Safeguard removal is necessary to perform activities such as adjustments, troubleshooting, maintenance, and installation (no specific operation modes exist for performing them) (I19).	17
3	P	Using safeguards is extra work (I3).	11
4	E	A safeguard reduces the visibility of the tools and activities such as working process, production, setting and so on (I15).	11
5	Mach.	Safeguards can be disabled easily and with little effort (I17).	11
6	Mach.	The required tools or keys for defeating are accessible in enterprises (I18).	11
7	Co	There is a lack of management commitment and managers either ordered, tolerated, encouraged or ignored circumvention (I36).	11
8	P	Safeguards are bypassed to save time carrying out the operations (I44).	11
9	B	Bypassing is a habit (I46).	11
10	P	Safeguards in place slow down the work process and production (I25).	10
11	E	There is impaired accessibility to the job and the tools (I58)	10
12	P	Profitability diminishes if the customer’s order is not met (I67).	10
13	Beh.	The risk of bypassing is underestimated or overlooked (I8).	9
14	Co	There are no enforcement or disciplinary actions for those who bypass safeguards (I37).	9
15	Beh.	Safeguards are not checked before operating the machine to ensure that they are in place (I62).	9

[1] E= Ergonomics, P= Productivity, Beh.= Behavior, Mach.= Machine or safeguarding, Co= Corporate Climate.

6.4.2.1 Leveraging the Probability Levels to Prioritize Machines and Safeguards Where Bypassing Needs to be Tackled

Dabbagh and Yousefi (2019) stated that an OHS risk management system is essential to identify and prioritize risks aiming to ensure that corrective or preventive measures are considered to reduce the negative consequences of risks. Therefore, this paper benefits this concept and presents a safety improvement prioritization method to prevent bypassing. The machines and then safeguards are prioritized based on the probability level of bypassing or the number or effects of incentives to bypass. This prioritization guides the OHS practitioners through their action plan to tackle that issue in order to prevent accidents. The companies could plan preventive measures based on the companies’ resource limitations, work conditions and policies. The prioritization is carried out in the following steps:

1. The machines that have at least one activity whose probability level of bypassing for its safeguard is “High”. Subsequently, the other machines with “Significant”, “Moderate”, and “Low” levels of

bypassing probability for their safeguards would be respectively placed in the next priorities with the same process.

2. For the machines whose safeguards have an identical probability level of bypassing, we consider a machine whose safeguards have more existing incentives.
3. If the number of existing incentives is equal for some machines, a machine that has more incentives with a significant effect "++" would be taken into account. Next, a machine that has more incentives with a slight effect "+".
4. After prioritizing the machines and safeguards in the companies, the incentives with a significant effect "++", and then, the incentives with a slight effect "+" are considered for defining the preventive measures in order to eliminate or reduce the incentives to bypass safeguards on each machine.

Table 6.6 depicts the prioritization of machines, as well as the prioritization of safeguards in each company to tackle bypassing. The numbers beside the name of the machines and also the safeguards specify their priority levels, which are sorted in ascending order, from the highest priority to the lowest.

Some safeguards exist for more than one activity (Appendix H). These safeguards were prioritized only once with the highest probability level of bypassing that they have. For instance, the interlocking guard is the existing safeguard during four activities on the wire drawing machine in company B. Since the probability level of bypassing for one of the activities is significant, it was considered in the first priority, therefore, we avoid prioritizing the same safeguard in the next levels. Additionally, the same method was used for the interlocking key in the control panel, the light curtain to avoid entering the area where the operator must put the bags and fence on Megabale press, the enclosure with an interlocking key in the control panel on the discharge conveyor, the gate with an interlocking key in the control panel and fence on the small bag press, and the light curtain on the wrapping machine in company C.

The Bagger and Robot cell in company A could be excluded from the prioritization process because these two machines were the machines manufactured by company A. In Section 6.4.1, it was concluded that the assessment tool was not practical for those machines. Coater #2 and Winder have the same priority in company D, because they have identical incentives with the same effect level.

To further prioritize incentives, we recommend that OHS practitioners consider in their company (i) the rate of repetition of incentives in each group of incentives, with either a significant effect or slight effect, (ii) the logic of the hierarchy of risk reduction measures in Giraud (2009); ISO 12100 (2010) from the most to least effective measures where some incentives have the same effect level. These references suggest starting, respectively, with inherently safe design measures, safeguarding, warning signs, safe work procedures, personal protective equipment (PPE), and training. Therefore, the OHS practitioners could first take preventive action to eliminate or reduce the incentives related to the machine or safeguarding and then the incentives related to the organization and individuals, (iii) a consensus among OHS practitioners and mainstream operators when some incentives associated with the same kind of preventive measures exist (Haghighi, Jocelyn, et al., 2019a).

Table 6.6 The prioritization of machines and safeguards

Company	**Prioritization of machine**[1]		**Prioritization of safeguards**[1]	
A	1. Bagger	H	1. Interlocking access gate	H
	2. Robot cell	H	1. Emergency stop safety function triggered by enclosure opening or E-stop button	H
	3. Conventional lathe machine	S	1. Interlocking removable guard (protection against projection: protection against fluid and falling metals)	S
			2. Interlocking movable chuck guard	M
			3. Protective curtain (screw bearing protection) – Interlocking removable access guard (access to the back of the machine	M
			4. Interlocking movable guard (protection of the other team members against projection of fluid or falling of metals)	L
	4. Grinding machine	M	1. Removable guard (protection against sparks)	M
			2. Movable guard (protection against projection)	M
	5. Drill press	M	1. Chuck guard	M
B	1. Galvanizing lead bath	S	1. Removable guard	S
	2. Wire drawing machine	S	1. Interlocking guard	S
	3. Hydraulic press	S	1. Protection rods	S
	4. Strander	L	1. Interlocking guard	L
C	1. Floor conveyor	H	1. Interlocking enclosure	H
			2. Guard	S
			3. Fence	M
	2. Megabale press	H	1. Interlocking key in the control panel	H

Table 6.6 The prioritization of machines and safeguards (continued)

Company	Prioritization of machine[1]		Prioritization of safeguards[1]	
			2. Light curtain to avoid entering the area where the operator must put the bags	M
			3. Fence	M
	3. Discharge conveyor	H	1. Enclosure with interlocking key in the control panel	H
	4. Small bag press	H	1. Gate with interlocking key in the control panel	H
			2. Fence	M
	5. Wrapping machine	H	1. Light curtain	H
D	1. Coater #1	S	1. Movable guard	S
			2. Fixed guard	S
	2. Lathe machine	S	1. Movable guard	S
	3. Coater #2 and Winder	S	1. Fixed guard	S

[1] H= High, S= Significant, M= Moderate, L= Low.

Section 6.4.2.2 recommends relevant preventive measures for the incentives identified in the case studies.

6.4.2.2 Suggestions for Preventive Measures

In this paper, we focus on the incentives that actually exist in the workplace and where the bypassing occurred. Table 6.7 presents the incentives that have had significant effects among the incentives listed in Appendix H and have caused the bypassing of safeguards in more than half of the companies visited. Therefore, the safeguards and subsequently, the machines with "Moderate" and "Low" probability levels of bypassing, would be excluded. For instance, the grinding machine and the drill press in company A as well as the strander in Company B would be ignored, because "Moderate" bypassing probability means that the safeguard is not bypassed and the potential incentives only exist and might cause bypassing in the future. In addition, "Low" bypassing probability means that there are no incentives to bypass (Table 6.2). The proper preventive measures for the incentives are suggested among the 82 solutions generated through a review carried out by Haghighi, Chinniah, et al. (2019). That review-based study reported that designers and manufacturers play significant roles to prevent bypassing. For instance, designers are required to comply with standards to provide well-designed and safe machinery. In addition, manufacturers should not overlook the quality of safety measures because of financial reasons (Haghighi, Chinniah, et al., 2019). Moreover, the employer is responsible for establishing OHS rules, providing safer machines and safeguards, and protecting the workers' health (Haghighi, Chinniah, et al., 2019; Zimmermann, 2007).

In the following, the preventive measures, as a sample, are explained in three categories including technical, organizational, and individual, as expressed by Haghighi, Chinniah, et al. (2019) as influential factors. In addition, the incentives (Table 6.7) written in parentheses could be eliminated or reduced through those solutions. The companies could generalize this approach in order to take preventive measures for other incentives with a slight effect and also for the potential incentives in the next steps. Furthermore, they could apply other preventive measures from the list of solutions existing in the above-mentioned study. These measures (e.g., implementing an OHS management system (e.g., ISO 45001 (2018)), developing a health and safety culture, considering defeating when defining the plans and goals) could generally have an overall effect in promoting the use of safeguards in the enterprises, and not only on a specific incentive. As Kim, Park, and Park (2016) stated, a culture of prevention is required to overcome OHS issues.

- Suggestions related to the technical factors are listed below to prevent bypassing:

1- Consider the special control modes, required operating modes, or alternate safeguarding devices such as an enabling device, or a hold-to-run device required during the activities in those control modes (I19, I20, I24, I58). Reduce the speed, for instance, to a quarter of the original full speed.

2- All of the safeguards and alternate safeguarding devices could be controlled by a safety smart controller. For instance, use interlocks, i.e., stopping movement, when guards are opened or removed (I17).

3- "New technological advances", "safety engineering aspects" and substantial expenses for controls could protect the safeguards against bypassing (I17, I19, I24, I43, I58).

4- Passive design and configurable design could be applied in order to mitigate the incentives to bypass (I17, I19, I24). Barriers, interlocks, two-hand devices, hold-to-run controls, and presence sensing devices are examples of passive design. For instance, movable guards could be replaced with interlocking guards with or without guard locking. As Schuster (2012) stated, the configurable design allows the worker to change the behavior of safety measures when a kind of energy is required for carrying out some activities such as maintenance, unjamming, robot teaching. In addition, a lockable system design locks the safety configuration selected and protects those configuration changes. This alternative could be used instead of lockout.

5- Communication between manufacturers and companies could help find technical solutions to facilitate operations without disabling safeguards (I19, I24, I58).

6- The accessibility of tools or keys for bypassing interlocks could be limited (I17, I18). For example, the interlocks or the panels containing the keys could be installed out of reach (e.g., up high) or be placed in a lockbox so that only supervisors would be able to access the keys to the controls.

7- “Error messages”, “audible or visible alarms” could be applied to machines to detect when safeguards are bypassed.

- Suggestions related to organizational factors are listed below to prevent bypassing:

1- Procedures could clarify that the safeguards should be in place and utilized (I46).

2- The workers could be involved during machine procurement and also other OHS issues (I36, I46). This shows that management pays attention to the workers' needs. With their participation, workers are encouraged to respect safety rules and procedures.

3- An employer is liable for respecting OHS regulations and ensuring that protection devices function sufficiently. He or she would not tolerate or order manipulation (I36). The employer will suffer legal troubles because of accidents due to bypassing.

4- The workers are prohibited from disabling safety measures (I46).

5- Appropriate supervision results in workers avoiding manipulation (I46). Furthermore, such monitoring could show management’s commitment at all organizational levels (I36).

6- Employers could provide the required training and retraining (I36). The Systematic Approach to Training (SAT) develops and organizes a training program to be in line with the “environmental and occupational hazards” faced in industry, the opinions of end-users and their training needs to meet learning objectives (Lagerstrom et al., 2019).

7- Management could clarify to workers that defeating is not tolerated and pay attention to workers’ recommendations (I36).

8- Managers could raise their awareness of hazards in order to improve their commitment (I36).

9- New machines could be provided or existing machines could be upgraded (I17, I18, I19, I20, I24, I43, I46, I58). For instance, automatic systems are suggested, such as the CNC lathe machine with full safety enclosures or fully automatic wire drawing machines. These improvements facilitate work, might change the workers' old habits, and they would not easily disable advanced safety measures.

10- Safety signs, images, and videos at toolbox talks could raise awareness (I46).

11- Clear and detailed guides could change workers' beliefs (I46).

- Suggestions related to individual factors are listed below to prevent bypassing:

1- Workers are responsible for using safeguards (I46).

2- Workers could promote an awareness of bypassing (I46).

These actions could help employees change their habits.

Companies could select above-mentioned modifications related to machinery and safeguards (technical modifications and upgrading) in consultation with a safety engineer in mechanical and electrical disciplines by investigating the machine and the condition of its safeguards in detail. Therefore, they could find suitable solutions. Moreover, as Jocelyn, Baudoin, Chinniah, and Charpentier (2014) stated, the users of the machine need to validate the safety function when they modify the machinery. When a company upgrades a machine or makes some changes to a machine or its safeguards (e.g., for example, an old machine in the company), there is no organization or body in the province of Quebec that would certify those modifications in order to ensure machine safety and only engineers are supposed to by law. Europe has such a certification. Ontario has a prestartup report. Therefore, the authors recommend that a body such as CNESST (Commission des normes, de l'équité, de la santé et de la sécurité du travail) could define a mechanism to inspect and verify the modifications in order to ensure that the safety of the machinery is sufficient and to certify those changes. In addition, the companies would not allow the machines and safeguards to be modified independently and without the supervision of a third party.

Table 6.7 List of actual incentives with significant effects existing in more than half of the companies

Actual incentives with significant effects	**Category**[1]
Safeguards can be disabled easily and with little effort (I17).	Mach.
The required tools or keys for defeating are accessible in enterprises (I18).	Mach.
Safeguard removal is necessary to perform activities such as adjustments, troubleshooting, maintenance, and installation (no specific operation modes exist for performing them) (I19).	P
Coping with faults would be more efficient with safeguard circumvention (I20).	P
Bypassing provides convenience and facilitates work (I24).	E

Table 6.7 List of actual incentives with significant effects existing in more than half of the companies (continued)

Actual incentives with significant effects	**Category[1]**
There is a lack of management commitment and managers either ordered, tolerated, encouraged or ignored circumvention (I36).	Co
Safeguard is bypassed to improve the flow of movement (I43).	E
Bypassing is a habit (I46).	Beh.
There is impaired accessibility to the job and the tools (I58).	E

[1] E= Ergonomics, P= Productivity, Beh.= Behavior, Mach.= Machine or safeguarding, Co= Corporate Climate.

6.4.3 Impact and Further Research

Ideally, machines are designed in such a way that they minimize the motivation to defeat safeguards by minimizing possible interference with activities during operation, maintenance, set-up and other phases of the machine's life cycle. The ISO 14119 design standard, which is related to the safety of machinery, lists technical measures to minimize defeating possibilities of interlocking devices.

In the literature that was consulted, very few tools exist to prevent bypassing and there is no indication that the few tools that do exist were tested: IFA (2011), DGUV (2013), and Suvapro (2007). Only the ISO 14119-inspired tool developed by Haghighi, Jocelyn, et al. (2019a) were tested, but only theoretically. Consequently, this paper contributes to the completion of the testing of Haghighi, Jocelyn, et al. (2019a)'s bypassing-related assessment tool by performing a practical testing of its performance through real industrial case studies at the machinery use phase. On the one hand, the testing results show the ISO 14119-inspired tool is appropriate in the real world. On the other hand, the results allow to present in this actual paper an improved version of this tool. According to the research team's observations during visits, as well as during their meetings and discussions with OHS practitioners in the companies, they found that the majority of incentives extracted from the review of scholarly references comply with what they observed in real workplaces.

The aforementioned bypassing-related assessment tool applies a preventive approach based on risk management principles and by identifying existing incentives (potential or actual) for avoiding the act of bypassing rather than taking corrective actions after the occurrence of manipulation. This could be achieved by the realistic identification of incentives to bypass from various categories of incentives. The findings (i) reveal that the tool is both practical and appropriate for the usage phase of a machine while identifying the incentives to bypass, as well as estimating the probability of bypassing; (ii) demonstrate how OHS practitioners, through the results of the tool, could effectively influence organizational decision-making to minimize incentives to bypass and subsequently to control the probability of bypassing in order to prevent bypassing-related accidents.

Therefore, the improved tool proposed can be used to assess incentives on existing machines. Even though the tool is dedicated to the machine use phase, those incentives can provide additional guidance to machine designers via input from end-users according to the feedback loop that is recommended by ISO 12100:2010 in the risk reduction process.

Future research could concentrate on the integration of the “probability of bypassing” as a parameter in OHS risk estimation tools. As such, ISO 12100 (2010) stated that the possibility of manipulation should be considered in risk estimation. In addition, the risk of harm could increase considerably by disabling interlocking devices (ISO 14119, 2013). Since the bypassing of safeguards might have an impact on the probability of harm and not the severity of harm, this case could be investigated further. In addition, the various risk estimation tools and relevant standards could be studied in order to integrate the type of assessment tool that is applicable (for example, risk assessment task-based tools and others).

A future research associated with measurable probability of bypassing, as an OHS leading key performance indicator (KPI), could inform on how well the enterprise performs in bypassing prevention or accident prevention.

Another future study on the current topic is recommended in order to formalize the bypassing situation. This would mean listing different kinds of bypassing situations (e.g., using a key, disabling sensors with metal, manipulating the programming and so on). In different companies, not all OHS practitioners have scientific knowledge related to this concept. Therefore, such formalization could help them gain a clear perception of what a bypassing situation concept is. In addition, the possibility of generalizing the tool to the other risk reduction measures in the hierarchy of (ISO 12100, 2010), including safe working methods such as lockout, warning signs and PPEs, could be investigated. The incentives for not applying each risk reduction measure could be identified.

Thanks to new technologies and Industry 4.0, the use of guards and protective devices could be promoted. This could also be an interesting avenue for further research. Industry 4.0 could allow the real-time monitoring of guards and the condition of protective devices. Therefore, Industry 4.0

elements could be studied to find a way for OHS practitioners and supervisors to ensure that the safeguards are in place, or they could detect the incentives for taking action immediately in order to prevent any possible serious injuries or fatalities. In addition, utilizing such new technologies, the communication between machine users, machine designers, and machine manufacturers could also be easier and also more efficient, relying on real-time information related to the incentives to bypass.

6.5 Conclusions

Standards and regulations require organizations to apply guards and protective devices if hazards cannot be inherently reduced or eliminated on machinery. Bypassing safeguards is forbidden during workers' interventions on machinery, because it increases the risk of harm and subsequently causes serious injuries and fatalities. This paper presented a case-oriented process to test and improve an ISO 14119-inspired tool to prevent bypassing safeguards on industrial machines. Four companies applied the tool to 18 machines and 37 activities. The four companies that participated are involved in different areas in the manufacturing sector, including equipment, iron and steel, horticulture and agriculture, as well as pulp and paper. OHS practitioners in the companies were the users of the tool for estimating the probability level of bypassing safeguards. Their feedback received after the application of the tool revealed their approval of the appropriateness of the tool, with 82% satisfaction in the machinery use phase. Moreover, their opinions suggest that the tool is sufficient for identifying the incentives among the existing list of incentives in the tool, as well as estimating the probability level of bypassing. Their opinions also suggested that the tool was more applicable to machinery at the usage phase (e.g., setting, maintenance, and operation) instead of machinery at the design phase. This statement reinforces the fact that the tool has always been dedicated, from the very start, to the use phase of machines.

Of course, the higher the number of case studies there are, the more accurate the overall satisfaction will be. However, the 82% result is totally acceptable, since four to ten cases are usually sufficient for case study-based methodologies (Eisenhardt, 1989). Therefore, the tool is useful to prevent bypassing on machinery at the use phase and it helps the companies find the existing incentives to bypass among different elements of their work environment (e.g., human, machine, procedures, and others). Subsequently, they could define suitable preventive measures in order to eliminate or reduce the corresponding existing incentives. Furthermore, some modifications were carried out on the tested assessment tool based on the companies' comments. The visual representation of the tool was changed so that the incentives were written in a horizontal format in order to respect ergonomic principles (e.g., posture) for the users of the assessment tool. More clarification of the incentives was taken into account. All modifications are available in the improved version.

Afterwards, this paper presented a process to prioritize (i) the machines and safeguards based on the four bypassing probability levels, and (ii) the incentives with significant and slight effects. In addition, some preventive measures were recommended for the incentives that had a significant effect as a sample. The prioritization process and the suggested preventive measures in Section 6.4.2.2 were explained in order to show the companies, as the users of the machines, how the results of the assessment tool could help them in their organizational decision-making. Decision-makers could plan and take sufficient actions by considering their company's strategies, policies and resource limitations. Therefore, they could make modifications to their equipment and improve the culture of safety as a highly reliable organization in order to (i) promote the use of safeguards, (ii) minimize bypassing-related accidents, and subsequently (iii) increase productivity within their company.

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CHAPTER 7 GENERAL DISCUSSION

The research results in relation to the critical review of the literature and the research contributions are discussed in this chapter.

7.1 Research contributions

Various safety-related standards associated with the design phase of machinery have been released over the years (ISO 12100, 2010; ISO 13851, 2002; ISO 13855, 2010; ISO 14119, 2013). The requirements of those standards emphasize the appropriate design and selection of protective devices (e.g., interlocking devices, two-hand control devices, and electro-sensitive protective equipment) to prevent defeating. Despite these standards, the literature has revealed that bypassing safeguards is a common problem in enterprises that use machines. In addition, bypassing safeguards has been identified as a contributing cause of work-related accidents. As such, these accidents may have irreparable consequences for employees and their employers. Therefore, this research aims to thwart bypassing in enterprises, as the machine users, by designing a preventative tool. A critical literature review, carried out in Chapter 2, identified the needs and gaps related to preventing bypassing in enterprises. To understand the importance of the bypassing problem, the definition of bypassing, relevant regulations and standards, incentives to bypass, and possible solutions to tackle this issue were reviewed in the literature (as explained in detail in Chapter 2 and Chapter 4). Then, an assessment tool dedicated to the machinery usage phase was developed, and the proposed tool was subsequently tested (explained in detail in Chapter 5 and Chapter 6). The original research contributions and their related research hypotheses to answer the research questions are elaborated upon as follows:

The first contribution related to the first hypothesis (*Having a tool that comprises the possible incentives to bypass, considering all elements of their work environment (e.g., procedures, equipment, operators, organization climate), will help OHS practitioners identify existing incentives to bypass on their machine at the use phase*)*:* To overcome bypassing, it needs to be understood why workers bypass safeguards. This issue may not be the only outcome of the workers' failure, but also the result of flaws in the work environment. Therefore, the incentives behind bypassing need to be identified, relying on a system-based approach in order to figure out the answer to the above-mentioned question (why workers bypass safeguards). A work environment as a system is comprised of various elements such as equipment, operators and their interactions, procedures, and more. Enterprises need to look for incentives to bypass from among all of these elements. Thus, this research carried out a literature review, as explained in Section 2.2.2 in order to identify the incentives to bypass. The references related to bypassing were studied. Each of those studies stated a limited number of incentives based on their scope. Since the references directly related to bypassing were limited, the references associated with machine safety were also reviewed in order to provide as complete of a list as possible containing incentives to bypass. This research identified an extensive list of 72 incentives to bypass, based on the literature. It also presented five main categories, including 1) ergonomics, 2) productivity, 3) machine or safeguarding, 4) behavior and 5) corporate climate for classifying those incentives. The contribution of this thesis provided useful insights into the incentives to bypass. It could also be used as a guideline for researchers and OHS practitioners in enterprises. Chapter 4 presented this guide, which was published in the first article (Haghighi, Chinniah, et al., 2019). In addition, the interdisciplinary list of incentives to bypass, grouped into five categories, serves as a foundation for designing an assessment tool. The use of a wide scope of incentives to bypass, as one of the prerequisites to develop a bypassing-related assessment tool as described further, makes it possible to identify all existing (actual or potential) incentives in the enterprise. By using this tool, enterprises can discover which category of incentive needs improvement in order to prevent bypassing. Moreover, they could also detect the occurrence of bypassing in the workplace. This contribution shows that the first hypothesis answers the first research question.

The second contribution related to the second hypothesis (*Providing an evidence-based list of preventive measures will equip the OHS practitioners to overcome bypassing*): In order to respond to the second research question, this research also contributed to identifying preventive measures to overcome bypassing, along with the first contribution. Various suggestions and recommendations regarding the prevention of bypassing were extracted by conducting a literature review in Section 2.2.2. It establishes a valuable source of 82 preventive measures. According to the collected improvement solutions, three categories were identified as the influencing factors to prevent bypassing in enterprises: 1) technical, 2) organizational, and 3) individual factors. Such achievements provide a guideline for researchers, as well as OHS practitioners, that could help them find suitable preventive measures to overcome bypassing. This fact confirms the second hypothesis. The above-mentioned guideline was reported in Chapter 4, published as the first thesis article (Haghighi, Chinniah, et al., 2019). Those findings were applied to case studies and the results, which are elaborated upon further, were presented in Chapter 6 as the third thesis article (Haghighi, Jocelyn, & Chinniah, 2020).

The third contribution related to the third hypothesis (*Developing a usage-oriented version of the IFA matrix (initially dedicated to the design phase) built according to construction rules of risk estimation tools will allow the incentive to bypass to be assessed*): This research revealed that most of the references in the literature only recommended several preventive solutions related to the design, manufacturing and usage phases. Before this research, only three tools existed in the literature to tackle bypassing. They are all dedicated to machinery design and their performance is unknown. Among those tools, the IFA assessment matrix suggested by ISO 14119 as an informative guide stands out. It inspired the design of an assessment tool for the usage phase of the machine in this research. An assessment tool was developed based on the wide scope of possible incentives (explained in the first contribution) that estimates the probability of bypassing. That holistic aspect of the tool distinguishes it from tools that have been suggested in previous studies (DGUV, 2013; IFA, 2011; ISO 14119, 2013; Suvapro, 2007).

These three contributions serve not only to design an ISO 14119-inspired assessment tool to prevent bypassing but also to improve the understanding of bypassing problem.

The fourth contribution related to the third hypothesis: Since the existing tools to tackle bypassing were limited, this research studied OHS risk estimation tools in order to develop an assessment tool that relies on scientific construction rules of OHS risk estimation tools. Chinniah et al. (2011) presented several construction rules on the basis of studying 31 risk estimation tools related to the safety of industrial machines. For instance, the authors recommended that the optimal number of levels for every risk parameter is between three and five levels for every risk parameter and for the risk level is at least four levels. This research integrated such information with the findings achieved from the third contribution in the process of developing bypassing-related assessment tool. Therefore, two parameters, including, “How is the bypassing situation?” and “the effect of incentives to bypass” were defined. Choosing three levels for each parameter helps minimize the subjectivity and produce more reliable results. The proposed tool in this research estimates the probability of bypassing through the above-mentioned parameters. Four levels were chosen for the probability of bypassing in order to generate more precise results that do not overestimate the probability of bypassing.

The third and fourth contributions confirm the third hypothesis.

The first, third, and fourth contributions served as a foundation to develop a bypassing-related assessment tool. Therefore, the following contributions are also relevant to the first and third research hypotheses.

The fifth contribution: This research developed a bypassing-related assessment tool to meet the needs identified in the literature aimed at preventing the bypassing of safeguards on industrial machinery. The tool was developed based on the required prerequisites as follows: (i) a wide scope of the incentives to bypass in five main categories (first contribution). (ii) The structure and logic adapted from an existing assessment matrix (IFA, 2011) in order to develop a tool for the use phase of the machine (third contribution). (iii) The influencing parameters and the number of levels for each parameter consistent with the construction rules of OHS risk estimation tools (fourth contribution). The OHS practitioners in enterprises are the users of the proposed tool at the use phase of machinery. The OHS practitioner identifies all activities and operation modes associated with the machine at step 1. An accurate list covering all activities in the machine lifecycle helps OHS practitioners have an assessment that is as precise as possible. This research has formalized a list of possible activities as a user guide based on Apfeld (2010), Chinniah et al. (2007), IFA (2011), ISO 12100 (2010) and ISO 14119 (2013). The second step lists the existing machinery safeguards for each activity. Step 3 investigates the existence of bypassing. At step 4, the OHS practitioner selects the existing incentives to bypass from among a wide scope of incentives formalized as mentioned in the first contribution. Finally, at step 5, the tool automatically estimates, through a formula, the probability of bypassing using the influencing parameters and their corresponding levels. Four levels, ranging from low to high, are considered in the probability of bypassing. Chapter 5, which is the second article in this thesis (Haghighi, Jocelyn, et al., 2019a) and Appendix A (Haghighi, Jocelyn, & Chinniah, 2019b) explain the inputs required to build a holistic assessment tool. Chapter 5 (Haghighi, Jocelyn, et al., 2019a) also proposes an assessment tool to estimate the probability of bypassing and presents all of the steps of the tool.

While preventing bypassing safeguards through a systematic approach, the bypassing issue should be integrated with the elements of the OHS management system in organizations such as training, auditing, management commitment and others, as discussed in Chapter 5. The proposed tool could also contribute to the Plan-Do-Check-Act (PDCA) procedure, since the OHS management system (ISO 45001, 2018) is founded on the PDCA cycle to achieve continuous improvement. In addition, the proposed tool could contribute to the decision-making process for problem-solving. The decision-making process is conducted through various tools that have been selected based on the aim of the decision-making; for example, SWOT diagram (Strengths, Weaknesses, Opportunities, and Threats) for strategic planning, the Ishikawa diagram to show the causes of a particular event, and others. The website www.cliffsnotes.com introduces the steps in the decision-making process as a generic approach for problem-solving, involving 1) a problem definition and the identification of limiting factors, 2) the development of potential alternatives, 3) analysis and the selection of the best alternative, 4) implementation of the decision and 5) evaluation and control. The proposed tool in this research is an assessment tool. As mentioned earlier in this research, the results of the application of the tool could help decision-makers. This means that the tool, on its own, is not a decision-making tool. It could be integrated into some steps of a decision-making process. For instance, the problem identification step is significant to make a true decision. The proposed tool could sufficiently contribute to this step in order to understand the bypassing problem and to identify the incentives to bypass accurately in enterprises. The proposed tool does not automatically recommend the exact preventive measures needed to overcome the bypassing situation in a company. However, this research suggests a list of preventive measures against bypassing. Consequently, decision-makers could define suitable preventive measures based on the identified incentives. The prioritization of preventive measures based on the probability levels of bypassing help decision-makers prioritize improvement actions. To tackle bypassing, enterprises need to pay attention to all of the identified incentives. This means that each incentive could be considered a problem, and one or more suitable preventive measures should be selected among the potential alternatives to eliminate or reduce that incentive. The OHS practitioner, along with the worker representative, could evaluate the effectiveness of the applied preventive measures. Finally, the tool could be applied to perform a regular assessment, and consequently to control the probability of bypassing.

The sixth contribution: The tools presented previously in the literature were design-oriented and had no performance indicators. Consequently, it was impossible to compare them on common grounds such as their performance. Therefore, the proposed tool was tested in two steps in order to ensure its usefulness and its appropriateness, as well as to ensure that it met the research objective. First, the feasibility of the tool in identifying the incentives to bypass and estimating the probability of bypassing was tested with five bypassing- related accident reports as the bypassing scenarios. Four of the accident reports were retrieved from the CNESST database and the other was retrieved from the NIOSH database. Chapter 5 (Haghighi, Jocelyn, et al., 2019a) reported the results of this test. Since this research developed the new tool for the machine use phase, the proposed tool was tested second in industry to ensure that it worked sufficiently in practice. The OHS practitioners in four companies in the manufacturing sector in the province of Quebec, Canada participated in this project and applied the proposed tool to 18 machines and 37 activities. All of the companies remarked that safeguards are bypassed temporarily in their plants (Table 7.1). A variety of machines and safeguards were chosen to carry out the estimation. The companies' feedback, gathered through a questionnaire, showed high-level satisfaction with the usefulness of the tool to prevent bypassing. This proves that the application of the tool in actual companies is possible. It also shows that the tool meets the two first hypotheses, i.e., it is suitable to help safety practitioners identify a wide scope of incentives to bypass as well as to take comprehensive measures to prevent bypassing.

Table 7.1 The percentages related to bypassing

Company	Percentage of machines with bypassed safeguards (%)	Percentage of bypassed safeguards (%)
A	10	30
B	10	1
C	20	20
D	33	1

Indeed, after receiving the results from the application of the tool from the OHS practitioners in the company, the research suggested a safety improvement prioritization method to show the companies how the results of the tool would be helpful when taking preventive actions. According to the prioritization process, the machines and subsequently the safeguards were put in order based on the estimated probability of bypassing from high to low, as well as the existing incentives, with significant effect and then slight effect. In the high and then significant levels of bypassing probability, a safeguard is bypassed and the actual incentives are present. Therefore, these two levels are, respectively, in order of priority. The enterprise needs to take actions for mitigating or removing the existing incentives. At a moderate level of bypassing probability, the safeguard is not bypassed and the OHS practitioner only observes some potential incentives to bypass. Therefore, a moderate level of bypassing probability would be at the next level of priority, which is to take preventive measures in order to avoid bypassing in the future. Finally, the low level of bypassing probability shows that incentives to bypass do not exist. After the process of prioritization, some technical, organizational, and individual measures were suggested for reducing or eliminating several existing incentives with significant effects in the companies as a sample. Those measures were chosen from among 82 preventive measures achieved in the second contribution. Chapter 6, which is the third paper (Haghighi et al., 2020), represents all of these findings.

The fifth and sixth contributions confirm that the first and third hypotheses respond to the first and third research questions. Therefore, the proposed tool allows the OHS practitioners to assess the existing incentives to bypass in the workplace in order to avoid bypassing safeguards of machines at the use phase.

The hierarchy provided through the safety improvement prioritization method could prompt the required actions to eliminate or reduce the incentives to bypass. Decision-makers in enterprises with limited resources for OHS, such as financial limitations, time limitations, and more, could prioritize improvement actions based on the various levels of bypassing probability. For instance, according to the incentives identified, the companies could consider organizational and individual measures as a short term solution if they have financial limitations. Then, technical measures could be considered as a long-term solution. Companies could assign the budget in their plans for more expensive measures because technical measures are more efficient than organizational and individual measures, based on previous studies (e.g, (Giraud, 2009; Haghighi, Chinniah, et al., 2019; IFA, 2011; ISO 12100, 2010))

OHS practitioners should verify the adequacy of implementing preventive measures to reduce the probability of bypassing. After implementing all of the necessary preventive measures, the proposed tool should be used again to update an estimation in the workplace assessed. The tool should show a reduced probability of bypassing. In addition, as an assessment tool, OHS practitioners could periodically use the tool to perform audits and assessments in the workplace. The latter is a dynamic place with different elements such as machines, individuals, procedures, and others. Each element could change over time, thus, the OHS practitioners could understand why bypassing-related accidents happen and could control the bypassing probability with a regular assessment.

Finally, the research results could influence organizational decision-making and help an organization move to a higher level of excellence by i) identifying the incentives to bypass, ii) eliminating or reducing the incentives to bypass by defining preventive measures based on the existing incentives that had been identified when applying the tool, iii) preventing bypassing and promoting the use of safeguards, iv) minimizing bypassing-related accidents, and subsequently v) increasing productivity.

7.2 Limitations

One of the limitations of this research is associated with the validation of the tool. The tool could be applied to more than four companies in order to validate it sufficiently. Chapter 5 announced that the tool would be validated in the end. However, the tool has only been tested as a result of time constraints and a lack of participants. Applying the tool was more time consuming than, for instance, completing a questionnaire or carrying out an interview. The research team had to schedule a meeting with the OHS practitioners in the enterprises in order to explain the project and the use of the tool. Those practitioners needed to apply the tool to various machines in their companies, to analyze and identify the incentives to bypass. Then, they would send the results and their feedback to the team. Afterwards, the team had to compile and analyze the data and information collected from the tool used by the practitioners. Therefore, applying it within more companies and on more machinery was not feasible because of the time limits of this research. In addition, finding and recruiting more participants proved to be difficult.

The tools from previous research studies were meant for the design, manufacturing and purchase phases. However, the proposed assessment tool is meant for the use phase of the machine. Therefore, evaluating and comparing the performance of the new tool with the previous tools is impossible to demonstrate whether the new tool has shown better performance than previous tools.

The results of the proposed bypassing-related assessment tool are based on the OHS practitioners' judgments and their evaluation when answering the question, "How is the bypassing situation?" and the level of "the effect of incentives to bypass." Therefore, the results are subjective, as with any other qualitative or semi-qualitative risk estimation tool. In order to help minimize the subjectivity, this research presents some points and recommendations: i) a careful definition has been provided for each effect level, ii) three levels have been taken into account for each parameter with regards to the bypassing situation and effect level of incentives, and iii) the tool had to be applied by competent OHS practitioners who are familiar with the machines and the work environment.

The proposed tool enables the identification of the incentives to bypass that need to be addressed to prevent bypassing. The tool does not present preventive measures. This research has explained how the results of the tool could help companies tackle bypassing in Sections 6.4.2.1 and 6.4.2.2 (prioritization of machines and safeguards, the suggestion of preventive measures for the identified existing incentives). Section 6.4.2.2 recommended several preventive measures as a sample among the list of 82 preventive measures. These solutions might be the first external layer of preventive measures. Thus, a deeper analysis of each existing incentive on each machine is necessary to define suitable preventive measures corresponding to each incentive by considering the machine conditions and company conditions. Such an analysis has not been carried out in this research.

7.3 Further research

This dissertation developed a bypassing-related assessment tool that could help the enterprises identify their existing incentives to bypass from among a wide scope of possible incentives considered in the tool. Next, they can take suitable preventive measures in order to eliminate or reduce the incentives and to prevent bypassing. In future research, the different bypassing situations (e.g., using a key, disabling sensors with metal, manipulating the programming and so on) could be formalized in the tool. It helps enterprises have a better understanding of bypassing situations, because not all OHS practitioners in enterprises have scientific knowledge related to this concept.

Validation of the proposed tool through a large number of case studies can be conducted as future research. In this research, the proposed tool was tested through five accident reports and then through its application in four companies in the manufacturing sector (applied to 18 machines and 37 activities). Therefore, applying the proposed tool to more case studies allows us to receive more feedback and to enrich the validation of the tool more sufficiently. As Moatari-Kazerouni et al. (2015) suggested that the practicality of a proposed OHS risk estimation tool could be validated if the tool was applied to many different situations.

Future research could focus on analyzing the results of applying the tool to one machine in a company. It could provide an opportunity to more deeply study the results, i.e., by scrutinizing the root causes of the incentives specifically identified for that machine in order to find suitable in-depth preventive measures for existing incentives. Then, the preventive measures could be defined in collaboration with OHS practitioners, workers' representatives, and the management within that company. This way provides detailed preventive measures that are no longer in the first external layer of solutions. In addition, the preventive measures could comply with machine conditions, the company's resources, and policies. The existing incentives and their interactions regarding the occurrence of bypassing on that machine would be taken into account to define preventive measures. Furthermore, the selected preventive measures could sometimes address more than one identified incentive on a machine.

Finally, the helpfulness of the preventive measures for the company to reduce or eliminate the incentives could be evaluated after a while. Therefore, the improvement of the machine and the company to control the bypassing probability could be observed. For example, “Clear and detailed guides could change workers’ beliefs” as a sample was suggested to eliminate “Bypassing is a habit” identified as an incentive in Chapter 6 . It is obvious that it is not enough to just have clear and detailed guides to overcome an incentive. Therefore, other technical, organizational, and individual measures should be picked out to eliminate this incentive on the target machine and in the target company by considering deeper existing incentives explaining that habit on that machine. For instance, upgrading the existing machine or safeguards could hinder risky habits. Limiting the accessibility of the tools or keys for bypassing and appropriate supervision could change the worker’s habit during operation. Utilizing safeguards should be clarified in the procedures, workers’ involvement during machine purchase, and also other OHS issues, training, toolbox talks could raise awareness. Subsequently, belief change and behavior change could be gradually observed. All of these actions could improve the culture of safety and safety perception at all organizational levels, day by day.

The possible incentives listed in the proposed tool are based on the literature. Further research could be conducted to reach a more comprehensive list of possible incentives to bypass, especially in behavioral and psychological fields. The research projects comprising human factors are complex. Therefore, understanding the profound reasons behind the incentives of bypassing is essential to identify the root causes and act on them to prevent bypassing. Hence, the proposed tool could be improved by researching in collaboration with psychological experts. This way, more detailed and extensive incentives related to the behavioral and psychological fields could be included in the proposed tool. Therefore, suitable measures could be taken into account through a deep understanding of the behavioral reasons for bypassing. Subsequently, a change of behavior and attitude could shape the positive habits that influence bypassing prevention (as suggested by Şimşekoğlu and Lajunen (2008) for road safety).

In addition, for further research, the bypassing concept in other fields such as a vehicle, aerospace, and others could be studied to identify more possible solutions to prevent bypassing. Other fields of research and inspiration could be approached to make relevant proposals for action, since some incentives found from the other fields in Section 2.1 have the same concept as several incentives among the list of 72 possible incentives provided in this thesis. For instance, the similarities with the reasons for not using seatbelts (Şimşekoğlu & Lajunen, 2008) are as follows. “Situational conditions” is identical to incentives related to the work condition such as I14 (production disturbance), I15 (lack of visibility), and I33 (to work faster). "Not believing in the effectiveness" is similar to I6 (workers feel that using safeguards are unnecessary). "Discomfort" is parallel with I26 (safeguards are difficult to use). "Having no habit" is equivalent to I46 (habit). In the maritime field, the bad quality of procedures increases procedure violations (Bye & Aalberg, 2020). This point is similar to I64 (inappropriate policies and procedures) contributing to the bypassing safeguards on machinery. The measures presented in the studies related to the other fields were similar to the several preventive measures listed in this thesis. For example, educating and training programs (Chen & Chen, 2011; Horswill & Coster, 2002; Pass, 2011; Şimşekoğlu & Lajunen, 2008) correspond to S34 and S42 organizational measures mentioned in this thesis. These measures are related to the provision of training and retraining to understand the necessity of using safety devices, as well as bypassing-related hazards. In addition, the training programs could also clarify (i) the benefits of applying safeguards, and (ii) how the safeguards affect bypassing-related accident prevention (as recommended by Şimşekoğlu and Lajunen (2008) for the vehicle safety). Reward mechanisms (Pass, 2011) is equivalent to S36 organizational measure, which comprise of establishing reward and disciplinary systems. Moreover, Horswill and Coster (2002); Pass (2011); Şimşekoğlu and Lajunen (2008) have suggested user-oriented design to minimize health and safety violations in various fields. This measure aligns with several technical measures presented in this thesis, including S9 (considering ergonomic concepts and users' convenience in design), S13 and S43 (communication between manufacturers and enterprises to make technical solutions for carrying out operations quicker and more convenient). Thus, the technical measures suggested among the 82 solutions from the literature for machinery safety should be assisted by the designer, by putting the human worker at the center of his or her design or modification for improvement, in order to prevent bypassing (as suggested by Pass (2011) for aerospace safety). In the field of road safety, Horswill and Coster (2002) suggested the purchase of low-powered vehicles, which results in drivers driving at lower speeds. This measure could be wisely adapted to machine safety, with the assistance of several measures related to the purchase of a new machine that were suggested among the 82 preventive measures, in order to select new machines with the minimum incentives, as well as to prevent bypassing. Consequently, the current research could be extended by comprehensively studying the applicability of the solutions from other fields, as well as by generalizing and adapting those solutions to safety machinery.

Integrating the “probability of bypassing” as a parameter in OHS risk estimation tools that would affect the probability of harm could be taken into account as future research. As ISO 12100 (2010) stated, the possibility of defeating should be considered when estimating risk. ISO 14119 (2013) also mentioned that the manipulation of interlocking devices could significantly increase the risk of harm.

In addition, generalizing the proposed bypassing-related assessment tool to risk reduction measures other than machinery safeguards, namely safe working methods (e.g., lockout), warning signs and PPEs could be another future study. The possible incentives for not applying each of those measures could be investigated.

Establishing new technologies conveyed by Industry 4.0, real-time monitoring guards and protective device conditions could help promote the use of safeguards. Indeed, having a real-time system detecting abnormal or unsafe states of safeguards could alert OHS practitioners who would then take action to correct the situation. Accordingly, further research is required to study how Industry 4.0 technologies could help OHS practitioners and supervisors ensure that guards or protective devices are in place or to proactively detect existing incentives to bypass in preventing bypassing-related accidents.

CHAPTER 8 CONCLUSION AND RECOMMENDATIONS

Risk assessment and risk reduction measures are essential to managing OHS-related risks. Workers may be exposed to dangerous situations if risk reduction measures were absent from an organization or were present but bypassed. Workers sometimes take shortcuts during maintenance and operations for productivity purposes. One of those shortcut actions is bypassing, which this dissertation expands upon. This research focuses on bypassing safeguards. Safeguards include guards and protective devices. They are the most efficient measures, after inherently safe design measures, in the hierarchy of risk reduction measures. Moreover, bypassing safeguards means removing guards or disabling protective devices on machinery, thus the machine continues operating in a manner that was not intended by the designer. Therefore, the bypassing of safeguards has been identified as one of the main contributing causes of occupational accidents.

The main aim of this dissertation is to prevent bypassing safeguards and to promote the use of safeguards in industry by designing, applying and improving upon a tool. This research has provided a reference repository on bypassing (including the definition of bypassing, related regulations and standards, workers' incentives to bypass, and possible solutions to tackle bypassing) in order to present a valuable source and guide for researchers and OHS preventionists. This research is original because unlike what does exist in the literature 1) it provides a wide scope literature-based review on the incentives to bypass categorized into five categories and preventive measures classified into three categories; 2) it not only develops a holistic bypassing-related assessment tool that is meant for the use phase of machinery, but also tests it. The proposed tool inspired by ISO 14119 is holistic because it was designed based on a wide scope of literature-based incentives to bypass, including 72 possible incentives, categorized into five categories concerning ergonomics, productivity, machine or safeguarding, behavior, and corporate climate. OHS practitioners in enterprises can apply the tool to machinery in order to identify the existing incentives in their workplace. They can also assess the bypassing situation and the effect of any incentive on three levels: 1) no effect, 2) slight effect, and 3) significant effect. Finally, the proposed tool has the ability to estimate the probability of bypassing as high, significant, moderate or low; 3) it presents the performance of the proposed tool by testing it with bypassing-related accident reports and applying it to real case studies (various machines in different companies).

This dissertation presents 82 literature-based preventive measures classified into three categories, including technical, organizational, and individual, as influential factors in order to tackle bypassing and to provide a safe workplace for workers.

While ensuring the appropriateness of the tool, the proposed tool was first tested with five scenarios, which were bypassing-related accident reports. Second, the tool was applied to real case studies (actual companies and real machinery) in the manufacturing sector with a variety of small-sized, medium-sized and large-sized companies. The companies' feedback about the application of the tool revealed a high-level (82%) of satisfaction. This level of satisfaction was achieved by totally applying the proposed tool to 18 machines and 35 activities. This sample included a variety of machines, such as a bagger, lathe machine, grinding machine, press, conveyor, wrapping machine as well as various activities, for instance, adjustment, machining, cleaning, monitoring, maintenance, troubleshooting and others. Furthermore, there were a variety of safeguards on machinery and the incentives to bypass were identified for each one during the application of the tool. For instance, the existing safeguards included a chuck guard, interlocking guard, fixed guard, movable guard, light curtain and others. The improved version of the tool was presented in this research. Moreover, applying the tool to other industrial sectors, as well as to more than four companies, is suggested in order to reinforce its practicality in various sectors and to sufficiently validate it. Finally, the results of the tool were applied in order to consider a prioritization process for improvement in safety, based on the probability levels of bypassing and the level of effect of incentives. Subsequently, preventive measures corresponding to the identified incentives were recommended among the 82 extracted solutions. This helps the OHS practitioners know how the proposed tool and its results could help prevent bypassing safeguards in their companies.

The bypassing issue should be integrated into the elements of an OHS management system (e.g. ISO 45001) in order to establish a systematic, preventive approach to tackle bypassing and to continuously improve a culture of safety in enterprises.

This dissertation serves 1) to develop a tool, 2) to improve the understanding of the bypassing problem, 3) as a base and a guide related to the bypassing issue for future research and for new ideas to further develop the proposed tool. The improved understanding of the bypassing problem enabled the design of a tool dedicated to the machine use phase. In addition, the results generated by the use of the tool can provide end users input (e.g., additional guidance) to machine designers according to the feedback loop recommended in the risk reduction process of ISO 12100:2010. That loop enables communication between machine users and machine designers for transferring the knowledge related to the incentives to bypass safeguards and for designing safe machinery. As in the road safety field, Horswill and Coster (2002) pointed out that the safety of traffic could be fostered by taking into consideration drivers' behavior feedback in the design of the vehicle.

BIBLIOGRAPHY

Adams, P. S. (2001). Using human factors to understand and improve machine safeguarding. *Applied Ergonomics*, CRC Press: Boca Raton, FL, USA, 69-75.

Alper, S. J., & Karsh, B.-T. (2009). A systematic review of safety violations in industry. *Accident Analysis & Prevention, 41*(4), 739-754.

Amponsah-Tawiah, K., & Mensah, J. (2016). Occupational health and safety and organizational commitment: evidence from the Ghanaian mining industry. *Safety and Health at Work, 7*(3), 225-230.

Apfeld, R. (2010). *Stop defeating the safeguards of machines.* Paper presented at the 6th International Conference Safety of Industrial Automated Systems, Tampere, Finland.

Apfeld, R., Huelke, M., Lüken, K., Schaefer, M., Paridon, H., Windemuth, D., . . . Pinter, H. (2006). Bypassing of protective devices on machinery (HVBG Report). *Hauptverband der gewerblichen Berufsgenossenschaften (HVBG), Sankt Augustin, Germany*.

Azadeh-Fard, N., Schuh, A., Rashedi, E., & Camelio, J. A. (2015). Risk assessment of occupational injuries using Accident Severity Grade. *Safety science, 76*, 160-167. doi:https://doi.org/10.1016/j.ssci.2015.03.002

Babcock Gove, P. (1993). *Webster's third new international dictionary of the English language unabridged*: Springfield, Mass. : Merriam Webster.

Backström, T., & Döös, M. (2000). Problems with machine safeguards in automated installations. *International Journal of Industrial Ergonomics, 25*(6), 573-585.

Bell, J. (2014). *Doing Your Research Project: A guide for first-time researchers*: McGraw-Hill Education, London, UK.

Blaise, J.-C., & Welitz, G. (2010). *Intervention on Machines: Operating Modes with "disabled safeguarding"*. Paper presented at the 7th International Conference Safety of Industrial Automated Systems, Montreal, Canada.

BLS. (2015). Labor Force Projections. *U.S. Bureau of Labor Statistics*.

Burlet-Vienney, D., Chinniah, Y., Bahloul, A., & Roberge, B. (2015). Design and application of a 5 step risk assessment tool for confined space entries. *Safety science*, *80*, 144-155.

Bye, R. J., & Aalberg, A. L. (2020). Why do they violate the procedures? – An exploratory study within the maritime transportation industry. *Safety science*, *123*, 104538. doi:https://doi.org/10.1016/j.ssci.2019.104538

Caputo, A. C., Pelagagge, P. M., & Salini, P. (2013). AHP-based methodology for selecting safety devices of industrial machinery. *Safety science*, *53*, 202-218. doi:https://doi.org/10.1016/j.ssci.2012.10.006

Charpentier, P. (2005). *Safety of machinery: experience feedback on automated accidents from the EPICEA database.* Paper presented at the 4th International Conference on Safety of Industrial Automated Systems, Chicago, Illinois, USA.

Charpentier, P., & Sghaier, A. (2012). *Industrial Robotic: Accident analysis and Human-Robot Coactivity.* Paper presented at the 7th International Conference Safety of Industrial Automated Systems, Montreal, Canada.

Chen, C.-F., & Chen, C.-W. (2011). Speeding for fun? Exploring the speeding behavior of riders of heavy motorcycles using the theory of planned behavior and psychological flow theory. *Accident Analysis & Prevention*, *43*(3), 983-990. doi:https://doi.org/10.1016/j.aap.2010.11.025

Chinniah, Y. (2009). Machine safety: Commonly observed problems in the manufacturing sector in Quebec. *Journal of Occupational Health and Safety, Australia and New Zealand*, *25*(5), 405-410.

Chinniah, Y. (2015a). Analysis and prevention of serious and fatal accidents related to moving parts of machinery. *Safety science*, *75*, 163-173.

Chinniah, Y. (2015b). *Causes of fatal and serious accidents involving machinery in Quebec.* Paper presented at the 8th International Conference Safety of Industrial Automated Systems, Königswinter, Germany.

Chinniah, Y., & Bourbonniere, R. (2006). Automation safety. *Professional Safety*, *51*(12), 26-33.

Chinniah, Y., Gauthier, F., Aucourt, B., & Burlet-Vienney, D. (2018). Validation of the impact of architectural flaws in six machine risk estimation tools. *Safety science*, *101*, 248-259. doi:https://doi.org/10.1016/j.ssci.2017.09.015

Chinniah, Y., Gauthier, F., Lambert, S., & Moulet, F. (2011). Experimental Analysis of Tools Used for Estimating Risk Associated with Industrial Machines, 77 pages. *Report R-684. Montreal: IRSST (Research Institute Robert-Sauvé Health and Safety).*

Chinniah, Y., Paques, J.-J., & Champoux, M. (2007). Risk Assessment & Reduction. *Professional Safety, 52*(10), 49-56.

CliffsNotes. Principles of management- The Decision-Making Process. <https://www.cliffsnotes.com/study-guides/principles-of-management/decision-making-and-problem-solving/the-decisionmaking-process> (Accessed 2020-11-18).

CNESST. (1990). Rapport d'enquête d'accident : accident mortel survenu à un travailleur, à l'emploi de la Compagnie Nalpac inc., le 20 septembre 1990 à Longueuil. Commission des normes, de l'équité, de la santé et de la sécurité du travail. <https://www.centredoc.cnesst.gouv.qc.ca/pdf/Enquete/ed002440.pdf> (Accessed 2018-05-16).

CNESST. (2006). Rapport d'enquête d'accident : accident mortel survenu à un travailleur le 11 octobre 2005 à l'entreprise Transpavé inc. située au 500, rue Saint-Eustache à Saint-Eustache. Commission des normes, de l'équité, de la santé et de la sécurité du travail. <https://www.centredoc.cnesst.gouv.qc.ca/pdf/Enquete/ed003606.pdf>(Accessed 2018-05-17).

CNESST. (2007). Rapport d'enquête d'accident : accident mortel survenu à un travailleur le 12 juillet 2006 à l'entreprise Les Systèmes de Drainage Modernes inc. 1288, Montée Léger à Les Cèdres. Commission des normes, de l'équité, de la santé et de la sécurité du travail. <https://www.centredoc.cnesst.gouv.qc.ca/pdf/Enquete/ed003655.pdf> (Accessed 2018-05-17).

CNESST. (2008). Rapport d'enquête d'accident : accident grave survenu à un travailleur le 19 juin 2007 à l'entreprise Québec Linge Service d'Uniformes située au 4375, rue de Rouen à Montréal. Commission des normes, de l'équité, de la santé et de la sécurité du travail. <https://www.centredoc.cnesst.gouv.qc.ca/pdf/Enquete/ed003697.pdf>(Accessed 2018-05-17).

Collier, D. (2014). New safety standards for interlocks with guards. *Paper Technology (Pilz Automation Technology, United States), 55*(1), 16-18.

Colquitt, J. A., LePine, J. A., Zapata, C. P., & Wild, R. E. (2011). Trust in typical and high-reliability contexts: Building and reacting to trust among firefighters. *Academy of Management Journal, 54*(5), 999-1015.

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches*: Sage publications.

CSAZ432. (2016). Safeguarding of machinery. *Canadian Standards Association,Toronto,Ontario, Canada*.

Dabbagh, R., & Yousefi, S. (2019). A hybrid decision-making approach based on FCM and MOORA for occupational health and safety risk analysis. *Journal of Safety Research, 71*, 111-123. doi:https://doi.org/10.1016/j.jsr.2019.09.021

Das, A., Pagell, M., Behm, M., & Veltri, A. (2008). Toward a theory of the linkages between safety and quality. *Journal of Operations Management, 26*(4), 521-535.

DGUV. (2013). Checklist machinery purchase (in German). Retrieved from https://stop-defeating.org/en/fuer-betreiber/ (Accessed 2017-02-10).

Doucet, P., & Brassard, A. (2010). *Designing and Building Machines Really Safe: How to Pass from Myth to Reality?* Paper presented at the 7th International Conference Safety of Industrial Automated Systems, Montreal, Canada.

Dźwiarek, M. (2004). An analysis of accidents caused by improper functioning of machine control systems. *International journal of occupational safety and ergonomics, 10*(2), 129-136.

Dźwiarek, M. (2019). Prevention of Defeating Interlocking Devices Associated with Guards. *Journal of KONBiN, 49*(3), 451-470.

Edwards, D. (1993). Accidents in computer controlled manufacturing plant and automated systems in Great Britain 1987–91. *study for Commission of the European Community, DG5, typescript, Health and Safety Executive, Birmingham*.

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of management review, 14*(4), 532-550.

Fan, D., Lo, C. K. Y., Ching, V., & Kan, C. W. (2014). Occupational health and safety issues in operations management: A systematic and citation network analysis review. *International Journal of Production Economics, 158*, 334-344. doi:10.1016/j.ijpe.2014.07.025

Fernández-Muñiz, B., Montes-Peón, J. M., & Vázquez-Ordás, C. J. (2009). Relation between occupational safety management and firm performance. *Safety science*, *47*(7), 980-991.

Fogg, B. (2009). *Creating persuasive technologies: an eight-step design process*. Paper presented at the Proceedings of the 4th International Conference on Persuasive Technology, Claremont, California, USA. https://doi.org/10.1145/1541948.1542005

Freedman, S. (2004). Issues in System Design. *Occupational Health & Safety*, *73*(5), 126. Retrieved from https://search.proquest.com/docview/220999296?accountid=220940695.

Gardner, D., Cross, J., Fonteyn, P., Carlopio, J., & Shikdar, A. (1999). Mechanical equipment injuries in small manufacturing businesses. *Safety science, 33*(1), 1-12.

Gauthier, F., Lambert, S., & Chinniah, Y. (2012). Experimental analysis of 31 risk estimation tools applied to safety of machinery. *International journal of occupational safety and ergonomics, 18*(2), 245-265.

Giraud, L. (2009). Machine Safety-Prevention of mechanical hazards: Fixed guards and safety distances. *IRSST, guide RG-597, Montréal, QC, Canada*.

Haghighi, A., Chinniah, Y., & Jocelyn, S. (2019). Literature review on the incentives and solutions for the bypassing of guards and protective devices on machinery. *Safety science*, *111*, 188-204. doi:https://doi.org/10.1016/j.ssci.2018.07.010

Haghighi, A., Jocelyn, S., & Chinniah, Y. (2019a). A holistic assessment tool to estimate the probability of bypassing safeguards on machinery. *Safety science*, *120*, 561-574. doi:https://doi.org/10.1016/j.ssci.2019.08.009

Haghighi, A., Jocelyn, S., & Chinniah, Y. (2019b). *Prerequisites for developing a machine safety bypassing-related assessment tool.* Paper presented at the 13th International Conference on Industrial engineering and QUALITA Conference (CIGI QUALITA Conference 2019), Montréal, Canada.

Haghighi, A., Jocelyn, S., & Chinniah, Y. (2020). Testing and improving an ISO 14119-inspired tool to prevent bypassing safeguards on industrial machines. *Safety, 6(3),* 42. doi: https://doi.org/10.3390/safety6030042

Hale, A., & Borys, D. (2013). Working to rule, or working safely? Part 1: A state of the art review. *Safety science, 55*, 207-221.

Hancock, D. R., & Algozzine, B. (2016). *Doing case study research: A practical guide for beginning researchers*: Teachers College Press, New York, NY, USA.

Haukea, M., Nabera, B., Bömera, T., Koppenborga, M., & Huelkea, D. M. (2015). *Crawling beneath and bypassing of three-dimensional detection zones on machines – Can the normative provisions be applied to modern protective devices such as camera systems?* Paper presented at the 8th International Conference Safety of Industrial Automated Systems, Königswinter, Germany.

Hesapro. (2013). The link between productivity and health and safety at work- Background research paper. Available online: *https://docplayer.net/7790585-The-link-between-productivity-and-health-and-safety-atwork.html*

HFRG. (1995). Improving Compliance with Safety Procedures: Reducing Industrial Violations. *Human Factors in Reliability Group, Published by Health & Safety Executive, HMSO London.*

Hietikko, M., Malm, T., & Alanen, J. (2011). Risk estimation studies in the context of a machine control function. *Reliability Engineering & System Safety, 96*(7), 767-774.

Hopkinson, J., & Lekka, C. (2013). Identifying the human factors associated with the defeating of interlocks on Computer Numerical Control (CNC) machines. *Health and Safety Laboratory: Buxton, UK. RR974 Research Report*.

Horswill, M. S., & Coster, M. E. (2002). The effect of vehicle characteristics on drivers' risk-taking behaviour. *Ergonomics, 45*(2), 85-104.

HSE. (2000). Reducing Error and Influencing Behavior. *HSG48 (HSE, London).*

Huelke, M., Stollewerk, R., Lüken, K., & Post, M. (2006). Safety from the testing of ergonomic machinery design. International Syposium, Nice, France.

IFA. (2011). The incentive to bypass protective devices on machinery. Retrieved from http://www.dguv.de/medien/ifa/en/pra/manipulation/explanations.pdf (Accessed 2016-09-09).

ISO 12100. (2010). Safety of Machinery – General Principles for Design – Risk Assessment and Risk Reduction. *International Organization for Standardization,Geneva, Switzerland*.

ISO 13851. (2002). Safety of machinery — Two-hand control devices — Functional aspects and design principles. *International Organization for Standardization,Geneva, Switzerland*.

ISO 13855. (2010). Safety of machinery — Positioning of safeguards with respect to the approach speeds of parts of the human body. *International Organization for Standardization,Geneva, Switzerland*.

ISO 14119. (2013). Interlocking devices associated with guards - Principles for design and selection. *International Organization for Standardization,Geneva, Switzerland*.

ISO 45001. (2018). Occupational health and safety management systems -Requirements with guidance for use. *International Organization for Standardization,Geneva, Switzerland*.

Järvinen, J., & Karwowski, W. (1993). *A questionnaire study of accidents in advanced manufacturing systems.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting, *37*, 1004-1008. doi:10.1177/154193129303701415

Jocelyn, S., Baudoin, J., Chinniah, Y., & Charpentier, P. (2014). Feasibility study and uncertainties in the validation of an existing safety-related control circuit with the ISO 13849-1: 2006 design standard. *Reliability Engineering & System Safety, 121*, 104-112.

Jocelyn, S., Chinniah, Y., & Ouali, M.-S. (2016). Contribution of dynamic experience feedback to the quantitative estimation of risks for preventing accidents: A proposed methodology for machinery safety. *Safety science, 88*, 64-75. doi:https://doi.org/10.1016/j.ssci.2016.04.024

Johnson, L. F. (1999). The luxury of machine guarding. *Occupational Health & Safety, 68*(12), 26-29.

Johnston, D., Pagell, M., Veltri, A., & Klassen, R. (2020). Values-in-action that support safe production. *Journal of Safety Research*, *72*, 75-91. doi:https://doi.org/10.1016/j.jsr.2019.11.004

Kabe, T. (2010). *Safety Service Engineering-An additional concept for safety of machinery.* Paper presented at the 7th International Conference Safety of Industrial Automated Systems, Montreal, Canada.

KANbrief. (2003). Bypassing of protective devices- a need for action by standardization bodies?. *KANBrief-Kommission Arbeitsschutz und Normung,* Sankt Augustin, Germany.

Kim, Y., Park, J., & Park, M. (2016). Creating a culture of prevention in occupational safety and health practice. *Safety and Health at Work, 7*(2), 89-96.

Lagerstrom, E., Magzamen, S., Brazile, W., Stallones, L., Ayers, P., & Rosecrance, J. (2019). A Case Study in the Application of the Systematic Approach to Training in the Logging Industry. *Safety, 5*(3), 13. doi:10.3390/safety5030043

Le parlement européen, e. l. c. d. l. u., EURO. (2009). Directive 2006/42/CE du parlement européen et du conseil du 17 mai 2006 relative aux machines et modifiant la directive 95/16/CE (refonte).

Leung, D., Rispoli, L., & Chan, R. (2012). Small, medium-sized, and large businesses in the Canadian economy: Measuring their contribution to gross domestic product from 2001 to 2008. In: Statistics Canada, Ottawa, ON, Canada.

Lo, C. K. Y., Pagell, M., Fan, D., Wiengarten, F., & Yeung, A. C. L. (2014). OHSAS 18001 certification and operating performance: The role of complexity and coupling. *Journal of Operations Management, 32*(5), 268-280. doi:10.1016/j.jom.2014.04.004

Lockton, D. (2013). *Design with intent: a design pattern toolkit for environmental and social behaviour change (Doctoral dissertation, Brunel University School of Engineering and Design PhD Theses).*

Lockton, D., Harrison, D., & Stanton, N. A. (2010). The Design with Intent Method: A design tool for influencing user behaviour. *Applied ergonomics, 41*(3), 382-392. doi:https://doi.org/10.1016/j.apergo.2009.09.001

Lockton, D., Nicholson, L., Cain, R., & Harrison, D. (2014). Persuasive technology for sustainable workplaces. *interactions, 21*(1), 58–61. doi:10.1145/2544170

Loeppke, R., Taitel, M., Richling, D., Parry, T., Kessler, R. C., Hymel, P., & Konicki, D. (2007). Health and productivity as a business strategy. *Journal of Occupational and Environmental Medicine, 49*(7), 712-721.

LSST, L. (2017). S-2.1 - Loi sur la santé et la sécurité du travail. *Publications du Québec*. Retrieved from http://legisquebec.gouv.qc.ca/en/ShowTdm/cs/S-2.1?langcont=fr

Lüken, K., Pardon, H., & Windemuth, D. (2006). Bypassing and defeating protective devices of machines–a multidimensional problem. *INRS–Hygiene et securite du travail*, *4*(205), 55-58.

Mattila, M., Tallberg, T., Vannas, V., & Kivistö-Rahnasto, J. (1995). Fatalities at advanced machines and dangerous incidents at FMS implementations. *International Journal of Human Factors in Manufacturing*, *5*(3), 237-250.

McConnell, S. M. (2004). Machine safeguarding: Building a successful program. *Professional Safety*, *49*(1), 18-27.

Moatari-Kazerouni, A., Chinniah, Y., & Agard, B. (2015). A proposed occupational health and safety risk estimation tool for manufacturing systems. *International journal of production research*, *53*(15), 4459-4475.

Morse, J. (1994). Designing funded qualitative research. *Handbook of Qualitative Research*, 220-235.

Neal, A., Griffin, M. A., & Hart, P. M. (2000). The impact of organizational climate on safety climate and individual behavior. *Safety science*, *34*(1), 99-109.

Neudörfer, A. (2012). Designing machines for safety; hazards-safety precautions. K.A. Schmersal GmbH. Available online: http://www.schmersal.com (Accessed 2016-09-21).

New York State Department of Health. (2004). *Fatality Assessment and Control Evaluation,Case Report 04NY013*.

NIOSH. (2004). A Machine Operator Dies When Crushed Inside a Knitting Machine. National Institute for Occupational Safety and Health (NIOSH). State Fatality Assessment and Control Evaluation (FACE) database. California Case Report: 04CA001.<https://www.cdc.gov/niosh/face/stateface/ca/04ca001.html> (Accessed 2016-11-28).

O'leary, Z. (2004). *The essential guide to doing research. Sage.*

OSHA3067. (1992). Chapter 2 - Methods of Machine Safeguarding (Accessed 03.2017). Retrieved from U.S. Department of Labor. https://www.osha.gov/Publications/Mach_SafeGuard/chapt2.html

OSHA-1910.212. Machinery and Machine Guarding (29 CFR 1910.212). *U.S. Department of Labor*, *https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9836*.

Pagell, M., Johnston, D., Veltri, A., Klassen, R., & Biehl, M. (2014). Is safe production an oxymoron? *Production and Operations Management, 23*(7), 1161-1175.

Parker, D., Manstead, A. S., Stradling, S. G., Reason, J. T., & Baxter, J. S. (1992). Intention to commit driving violations: An application of the theory of planned behavior. *Journal of applied psychology, 77*(1), 94.

Parker, D. L., Brosseau, L. M., Samant, Y., Xi, M., Pan, W., Haugan, D., & The Study Advisory, B. (2009). A Randomized, Controlled Intervention of Machine Guarding and Related Safety Programs in Small Metal-Fabrication Businesses. *Public Health Reports, 124*(Suppl 1), 90-100. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2708660/

Pass, J. (2011). *Deviance in space habitats: A preliminary look at health and safety violations.* Paper presented at the 2011 Space, Propulsion and Energy Sciences International Forum, SPESIF-2011, March 15, 2011 - March 17, 2011, College Park, MD, United states.

Perry, C. (1998). Processes of a case study methodology for postgraduate research in marketing. *European journal of marketing, 32*(9/10), 785-802.

Peter, N., Lungfiel, A., Nischalke-Fehn, G., & Trabold, R.-J. (2013). A virtual reality pilot study towards elevating work platform safety and usability in accident prevention. *Safety Science Monitor, 17*(1), 2.

Pratt, S., & Hard, D. (1998). Injury Risk Factors Associated with AgriculturalWorkplace Fatalities. *Journal of agricultural safety and health, 4*(5), 29-38. Retrieved from http://elibrary.asabe.org/abstract.asp?aid=15372&t=3

Racz, S. G., Breaz, R. E., & Cioca, L. I. (2019). Evaluating Safety Systems for Machine Tools with Computer Numerical Control using Analytic Hierarchy Process. *Safety, 5*(1), 11. doi:10.3390/safety5010014

Reason, J. (1990). *Human error*: Cambridge University Press.

Reason, J. (1994). Errors, outcomes and circumventions: A reply to Dougherty. *Reliability Engineering & System Safety, 46*(3), 297-298. doi:https://doi.org/10.1016/0951-8320(94)90127-9

Reason, J. (2000). Human error: models and management. *BMJ: British Medical Journal, 320*(7237), 768.

Reason, J. (2016). *Managing the risks of organizational accidents*: Routledge (First publishing 1997 by Ashgate Publishing Ltd, London).

Roudebush, C. (2005). Machine safeguarding: A process for determining tolerable risk. *Professional Safety, 50*(10), 20-24. Retrieved from Retrieved from https://search.proquest.com/docview/200402498?accountid=40695

RSST, L. (2017). S-2.1, r. 13 - Règlement sur la santé et la sécurité du travail. *Publications du Québec*. Retrieved from http://legisquebec.gouv.qc.ca/fr/showdoc/cr/S-2.1,%20r.%2013

Samant, Y., Parker, D., Brosseau, L., Pan, W., Xi, M., & Haugan, D. (2006). Profile of machine safety in small metal fabrication businesses. *American journal of industrial medicine, 49*(5), 352-359. doi:10.1002/ajim.20294

Schuster, G. (2012). Improving Manufacturing Performance. *Professional Safety, 57*(4), 62-64.

Shaw, S. (2010). *Machinery accidents–Contributory factors.* Paper presented at the 6th International Conference Safety of Industrial Automated Systems, Tampere, Finland.

Sherrard, L. (2007). Things everyone should know about machine guarding. *Occupational health & safety (Waco, Tex.), 76*(5), 112-113.

Şimşekoğlu, Ö., & Lajunen, T. (2008). Why Turks do not use seat belts? An interview study. *Accident Analysis & Prevention, 40*(2), 470-478. doi:https://doi.org/10.1016/j.aap.2007.08.002

Smallman, C., & John, G. (2001). British directors perspectives on the impact of health and safety on corporate performance. *Safety science, 38*(3), 227-239.

Stop-defeating. Prevent defeating of safeguards on machinery <http://www.stop-defeating.org>.

Suvapro. (2007). Liste de contrôle: STOP à la manipulation des dispositifs de protection. Retrieved from https://extra.suva.ch/webshop/56/56A6469AB0342C70E10080010A63035B.pdf (Accessed 2016-09-14)

Tochio, M., Nakayama, K., Arai, T., Nonoaka, S., Shiomi, M., Knamaru, H., . . . Mukaidono, M. (2012). *The Improvement of Industrial Safety achieved by the Introduction of Safety Assessor / Safety Basic Assessor Qualification System and its International Operations.* Paper presented at the 7th International Conference Safety of Industrial Automated Systems, Montreal, Canada.

Vautrin, J., & Dei-Svaldi, D. (1989). Accidents du travail sur sites automatisés. Évaluation d'une prévention technique. *Cahiers de Notes Documentaires, 136*, 445-453.

Yasui, T., Obata, N., Fukui, T., Matsumoto, A., & Fujita, T. (2010). *Development of Interlock Switch with Lock Function for the improved Safety in Consideration of Failure.* Paper presented at the 7th International Conference Safety of Industrial Automated Systems, Montreal, Canada.

Zimmermann, A. (2007). SuvaPro-STOP à la manipulation des dispositifs de protection. *Benefit, 3*, 9-10.

APPENDIX A – CONFERENCE PAPER: PREREQUISITES FOR DEVELOPING A MACHINE SAFETY BYPASSING-RELATED ASSESSMENT TOOL

This article was presented at 13 th International Conference on Industrial engineering and QUALITA Conference (CIGI QUALITA Conference 2019) , Montreal, Canada in 2019.

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Abstract

Bypassing safeguards on machinery can lead to serious and fatal accidents. Organizations must pay attention to incentives for bypassing and ways in which bypassing could be prevented. The objective of this paper is to prepare required inputs to build a holistic assessment tool. Identified prerequisites are: i) the structure and logic adapted from an existing assessment matrix. ii) The influencing parameters on estimating the probability of bypassing and the number of levels for each parameter. "The situation of bypassing" and "effect level of incentives" consist of three levels that are considered to be influencing parameters. iii) A comprehensive scope of the incentives involving ergonomics, productivity, behavior, machine or safeguarding, and corporate climate is taken into account. This distinguishes the new holistic tool from tools that have been suggested in previous studies. In addition, four levels that indicate the probability of bypassing are defined as high, significant, moderate, and low to reduce variability during the estimation. Therefore, a consideration of these required inputs provides sufficient foundation for developing an assessment tool in future research, which will use an Excel spreadsheet to estimate the probability of bypassing. The estimation results should help machine users determine and prioritize improvement actions to prevent bypassing.

Keywords: machine safety, bypassing guards and protective devices, incentives to bypass, assessment tool, occupational health and safety

A.1 Introduction

During the risk management process, risk reduction measures are defined and applied to reduce risk to an acceptable level. Applying such measures helps prevent accidents and provides a safe workplace. Unfortunately, a widespread problem called bypassing guards and protective devices (safeguards) is observed in enterprises. Apfeld (2010); Apfeld et al. (2006); IFA (2011) defined bypassing as “rendering inoperative the protective devices with the result that a machine is operated in a manner not intended by the designer or without the necessary safety measures.” Bypassing is one of the main contributing factors in machine-related accidents in various countries and in many different industries. For example, almost 37% of all protective devices on metalworking machines in Germany have been bypassed (Apfeld, 2010; Apfeld et al., 2006; IFA, 2011). In 2008, more than 10,000 accidents and eight deaths occurred due to bypassing protective devices in Germany. In half of the enterprises in Switzerland, protective devices on machinery have been defeated (Zimmermann, 2007).

All of these examples demonstrate the significance of bypassing, which can cause fatalities and serious injuries, including crushing. Therefore, some studies have proposed certain tools to tackle bypassing protective devices. The IFA (2011) designed an assessment matrix for designers. The matrix assesses the incentives behind bypassing. A checklist was suggested by DGUV (2013) for the procurement of machinery that provides the minimum incentives to bypass protective devices during the purchase phase. Suvapro (2007) proposed a general checklist that helps the hazards of bypassing to be controlled in order to stop the circumvention of protective devices. Each of the above-mentioned tools contributes to dealing with bypassing guards and protective devices, even though those tools have some limitations. For instance, the IFA matrix encompasses limited incentives for an assessment in the design phase and the DGUV checklist only focuses on the machine procurement step. Therefore, the objective of this study is to prepare the required inputs to develop a holistic assessment tool in future research that fills a gap that exists in previous tools. The suitable outputs of this study provide the prerequisites for developing the new assessment tool, which will deal with the aspects that influence bypassing beyond just equipment. These include the lack of commitment by management, workers’ habits, a lack of training and lack of disciplinary action. A comprehensive assessment of the incentives to bypass is accomplished by considering 72 possible incentives, based on a comprehensive review carried out by Haghighi, Chinniah, et al. (2019).

The remainder of this paper is organized as follows: Section A.2 provides a literature review about bypassing in order to guide the contributions of the paper. Section A.3 outlines the research methodology. Section A.4 describes the construction of a holistic assessment tool. Section A.5 provides a discussion. Finally, Section A.6 concludes the paper.

A.2 Literature review

In the hierarchy of risk reduction measures (ISO 12100, 2010), guards and protective devices are the most efficient measures after inherently safe design measures. In the context of this paper, bypassing guards and protective devices means removing guards or disabling protective devices on machinery. Various papers have revealed that bypassing is one of the main contributing factors in the occurrence of machine-related accidents (Apfeld et al., 2006; Backström & Döös, 2000; Charpentier, 2005; Charpentier & Sghaier, 2012; Chinniah, 2009, 2015a; Chinniah & Bourbonniere, 2006; Chinniah et al., 2007; Dźwiarek, 2004; Gardner et al., 1999; Hopkinson & Lekka, 2013; Huelke et al., 2006; Järvinen & Karwowski, 1993; KANbrief, 2003; Mattila et al., 1995; D. L. Parker et al., 2009; Pratt & Hard, 1998; Samant et al., 2006; Shaw, 2010; Vautrin & Dei-Svaldi, 1989; Zimmermann, 2007) and ((Edwards, 1993) cited in (Backström & Döös, 2000)).

The HVBG[22] report was the first study to present trustworthy statistics and information on the bypassing of protective devices (Apfeld et al., 2006). That study was carried out in two phases. During the first phase, 940 general questionnaires were distributed in the metalworking sectors in Germany and were returned to estimate the amount of defeating protective devices that had occurred. In the second phase, information related to reasons for bypassing (e.g. to obtain a faster work process, greater productivity, better visibility, better audibility, less physical effort) was collected after a special questionnaire about 200 machines had been completed. Finally, some solutions concerning the psychological, ergonomic, organizational and technical aspects of defeating were suggested. Later, the IFA (2011) applied some incentives identified by Apfeld et al. (2006) to create its assessment matrix for designers, which is detailed extensively in Section A.4.1. Zimmermann (2007) stated that unplanned inspections and time-saving (22.8%), unsuitable machines (15.4%), and poor ergonomics (15.4%) are the most probable incentives behind circumvention. Then, a campaign was launched in Switzerland to boost controls to prevent the manipulation of protective devices. Hopkinson and Lekka (2013) carried out research in two phases to identify operators' motives to defeat the interlocks on Computer Numerical Control (CNC) machines among small and medium-sized enterprises (SMEs). Those authors revealed three factors influencing an operator's behavior towards bypassing; these are predisposing (e.g. individual characteristics), reinforcing (e.g. reward and punishment) and enabling

[22] HVBG is the German Federation of Institutions for Statutory Accident Insurance and Prevention; it stands for Hauptverband der gewerblichen Berufsgenossenschaften.

(e.g. environment and system). Poor machine design, lack of visibility, impaired accessibility to the tools or the job and poor usability were identified as the most frequent reasons cited for defeating interlocks. Haghighi, Chinniah, et al. (2019) recently accomplished a review of the incentives to bypass and preventive solutions for the issue of bypassing. They extracted and classified 72 possible incentives into five main categories: 1) ergonomics, 2) productivity, 3) machine or safeguarding, 4) behavior, and 5) corporate climate, which are explained in detail in Section A.4.3. In addition, the extracted improvement proposals are categorized into technical, organizational, and individual factors as the influencing factors that should be taken into account in the design, machine manufacturing, and usage phases. Some solutions are suggested in various studies to promote the use of guards and protective devices. Some of the most frequent recommendations expressed by the authors are (i) improving the design of machines and safeguards, (ii) considering employees' points of view for machine procurement, (iii) providing adequate supervision, (iv) training employees to understand the necessity of using safety measures, and (v) periodic inspections performed by managers and supervisors to ensure that interlocks were enabled (Adams, 2001; Apfeld et al., 2006; Chinniah, 2015a; DGUV, 2013; Dźwiarek, 2004; Freedman, 2004; Hopkinson & Lekka, 2013; IFA, 2011; ISO 12100, 2010; ISO 13855, 2010; ISO 14119, 2013; Järvinen & Karwowski, 1993; Johnson, 1999; KANbrief, 2003; Lüken et al., 2006; Mattila et al., 1995; McConnell, 2004; Neudörfer, 2012; D. L. Parker et al., 2009; Peter et al., 2013; Pratt & Hard, 1998; Roudebush, 2005; Schuster, 2012; Sherrard, 2007; Suvapro, 2007; Zimmermann, 2007) and (Department of Health State of New York, 2004) cited in (Hopkinson & Lekka, 2013)).

To prevent defeating in the design phase, ISO 12100 (2010) considered the possibility of bypassing safety measures as one of the aspects during risk estimation. The required preventive measures were provided to decrease the possibility of defeating interlocking devices (ISO 14119, 2013). Guards and protective devices should not be easily defeated (CSAZ432, 2016; Le parlement européen, 2009). The manipulation of a protective effect of a two-hand control should be difficult (ISO 13851, 2002). The circumvention of electro-sensitive protective equipment should be avoided (ISO 13855, 2010).

In addition to the assessment matrix proposed by IFA (2011), a general checklist was designed by Suvapro (2007) that could control the hazards of manipulation. That checklist includes four sections: (i) new machine purchases, (ii) normal functions, (iii) specific functions and maintenance, (iv) human behavior, training and organization. DGUV (2013) proposed a checklist for purchasing a machine with minimum incentives to bypass protective devices. Moreover, the stop-defeating.org website provides guidelines and shares information that is helpful for manufacturers, suppliers and users in preventing the bypassing of guards and protective devices.

None of these studies have proposed a tool for companies, who are the machines' users who will have the most interaction with the machine during its lifecycle. In addition, previous studies did not consider comprehensive parameters that influence bypassing. For instance, the IFA matrix is comprised of limited incentives for the assessment. The DGUV checklist is only applied to the machine procurement step.

Chinniah et al. (2011) studied 31 risk estimation tools related to the safety of industrial machines. Between three and five levels are suggested for every parameter and no less than four risk levels. Moatari-Kazerouni et al. (2015) define five levels for risk parameters in the proposed OHS risk estimation tool for manufacturing systems. Five levels for the parameters and four levels for risk are defined in the design of a five-step risk assessment tool for the confined space entries (Burlet-Vienney et al., 2015). Those results are considered in this study to select a suitable amount of levels of parameters for developing the new assessment tool.

A.3 Research methodology

Companies need to identify the incentives for bypassing guards and protective devices in order to consider suitable corrective and preventive measures to reduce or eliminate these incentives. This paper aims to prepare the required inputs to model a holistic assessment tool. Our contribution to this goal is as follows:

- To adapt and expand the structure and logic of the assessment matrix developed by IFA (2011) to construct a new assessment tool based on the findings of Haghighi, Chinniah, et al. (2019) related to 72 incentives (a comprehensive scope of incentives) to bypass guards and protective devices, as extracted from a review of various studies.
- The output of this paper is a suitable input for the design of an assessment tool to estimate the probability of bypassing guards and protective devices on machinery.

The overall research methodology is as follows:

(1) The IFA assessment matrix (IFA, 2011) is studied to consider the structure and the logic of the matrix.

(2)The OHS-related risk estimation tools are reviewed in order to define the parameters, the number of levels for the parameters, and the probability of bypassing.

(3)Seventy-two possible incentives to bypass are classified into five main categories: 1) ergonomics, 2) productivity, 3) machine or safeguarding, 4) behavior, and 5) corporate climate, based on the comprehensive review of Haghighi, Chinniah, et al. (2019). These are considered in building the new assessment tool.

A.4 The construction of the holistic assessment tool

According to the studies reviewed, we understood the necessity of having a tool that could help enterprises to identify the existing incentives to bypass, as well as to define the preventive actions to eliminate or reduce those incentives, based on the probability levels of bypassing the guards and protective devices on machinery. Therefore, three inputs were considered in helping us construct the assessment tool. These inputs are described in the following section.

A.4.1 Adaptation from the IFA assessment matrix

IFA (2011) developed an assessment matrix for designers to identify the benefits that may exist in the absence of protective devices. After defining the tasks and relevant operating modes, the matrix asks two questions: 1) is the task feasible in the determined operating mode? and 2) can the task be performed without defeating? “Yes” or “No” options are suggested to answer those questions. In the next step, a summary of the incentives in the HVGB report (Apfeld et al., 2006) is taken into account. Three possible entries are proposed to determine whether there is a benefit to performing each task in the absence of protective devices. Those entries include “no benefit,” “minor benefit” and “significant benefit”. If the “Yes” option is chosen for the first two questions noted above, a benefit would be marked with one of those entries.

Finally, the IFA assessment matrix defines three levels, but this time for the incentive to bypass (ITB):

- “Low”: there are no benefits for a task.
- “Present”: There is at least one minor or significant benefit for a task.
- “High”: the task is unallowable in the operating mode or the task is not possible without defeating. Therefore, improvements in machine design are required.

Since the design of the new tool is inspired by the IFA assessment matrix, the new tool adapts the formula that IFA (2011) defined for its assessment matrix. In addition, the new tool indicates the probability of bypassing in four levels explained in Section A.4.2, while the IFA assessment matrix describes the ITB in the three levels mentioned above.

A.4.2 Selection of parameters and number of levels for the parameters and probability of bypassing

Since the proposed tool concerns the estimation of the probability of bypassing and there is limited research directly related to bypassing, a review of some OHS-related risk estimation tools was considered relevant to inform the choice of risk parameters as well as the number of levels describing the parameters and the risk. Chinniah et al. (2011) studied 31 risk estimation tools related to the safety of industrial machines. The authors presented several construction rules. For instance, they recommended considering between three and five levels for every risk parameter and using no less than four risk levels as the optimal number of levels. Moatari-Kazerouni et al. (2015) designed an OHS risk estimation tool for manufacturing systems. They considered five levels for each parameter and the risk levels. Burlet-Vienney et al. (2015) proposed parameters and risk with five levels and four levels, respectively. Therefore, the parameters that are used to model the holistic assessment tool are presented below.

(1) Evaluating the bypassing situation of a machine in an enterprise. Three entries are taken into account for this parameter, which include "not bypassed and no incentives," "not bypassed and potential incentives," and "bypassed and actual incentives".

(2) Assessing the level of the effect of incentives to bypass on the probability of bypassing in the enterprise. This proposed parameter is scaled onto three levels, which include "no effect," "slight effect" and "significant effect".

The above-mentioned parameters and the number of levels for each are applied to determine the probability level for bypassing. Thus, they should be considered in the formula (which would be performed by an Excel function) to generate a corresponding probability level for bypassing. Four levels are considered for the probability of bypassing guards and protective devices on machinery as high, significant, moderate and low.

A.4.3 A comprehensive scope of incentives to bypass

Since information related to incentives to bypass and their categories presented by Haghighi, Chinniah, et al. (2019) are extensively used to develop the assessment tool, a summary of their research is provided here to describe how the incentives are considered in constructing the most influencing parameter to estimate the probability of bypassing.

Guards and protective devices are bypassed. This has drawn the attention of organizations and researchers in order to determine the incentives behind bypassing. Therefore, documents were reviewed by Haghighi, Chinniah, et al. (2019) to gain a better and deeper understanding of the incentives for bypassing guards and protective devices. Twenty-four papers and other types of references are reviewed (Adams, 2001; Apfeld et al., 2006; Backström & Döös, 2000; Charpentier & Sghaier, 2012; Chinniah, 2009, 2015a, 2015b; Chinniah & Bourbonniere, 2006; Freedman, 2004; Gardner et al., 1999; Hopkinson & Lekka, 2013; Huelke et al., 2006; IFA, 2011; ISO 12100, 2010; Johnson, 1999; KANbrief, 2003; Lüken et al., 2006; Mattila et al., 1995; McConnell, 2004; Neudörfer, 2012; Roudebush, 2005; Schuster, 2012; Sherrard, 2007; Zimmermann, 2007). Seventy-two potential incentives to bypass were extracted and grouped into five categories, as is explained in the following (Table A. 1 to A. 5). The exact statements proposed by Haghighi, Chinniah, et al. (2019) would be applied to model the new assessment tool.

A.4.3.1 Ergonomics

This group includes the incentives related to the limitations that machines, tasks and equipment engender for workers. Poor visibility, inadequate lighting in the workplace, poor audibility, and poor accessibility to the job and the tools are examples of incentives in the ergonomics category.

Table A. 1 Incentives to bypass safeguards related to the ergonomics category

NO.	Incentives to bypass
1.	A safeguard reduces the visibility of the tools and activities such as working process, production, setting and so on.
2.	Removing and installing safeguards frequently for lubrication is tedious.
3.	Bypassing provides convenience and facilitates work.
4.	A safeguard limits adequate lighting in a workplace.
5.	Machinery and safeguards are not user friendly and have poor ergonomics.
6.	There is not enough workspace when using a safeguard.
7.	A safeguard is bypassed for better audibility.
8.	A safeguard is bypassed to require less physical effort.
9.	A safeguard is bypassed to reduce the rate of travel.
10.	A safeguard is bypassed to facilitate movement.

Table A. 1 Incentives to bypass safeguards related to the ergonomics category (continued)

NO.	Incentives to bypass
11.	A safeguard is bypassed to improve the flow of movement.
12.	A safeguard is bypassed because of stress.
13.	There is impaired accessibility to the job and the tools.
14.	Metabolic energy consumption will be reduced through bypassing.

A.4.3.2 Productivity

This category encompasses incentives related to the existence of obstacles to consuming organizational resources effectively and efficiently. Some incentives, such as time pressure, financial pressure, greater productivity, the use of safeguards as being extra work, and working faster are several incentives associated with the productivity category.

Table A. 2 Incentives to bypass safeguards related to the productivity category

NO.	Incentives to bypass
1.	There is a lot of work to carry out.
2.	Reaching into a hazardous zone several times to do the work.
3.	Using safeguards is extra work.
4.	Using safeguards is time-consuming.
5.	Safeguards disturb the work process and production.
6.	Safeguard removal is necessary to perform activities such as adjustments, troubleshooting, maintenance, and installation (no specific operation modes exist for performing them).
7.	Coping with faults would be more efficient with safeguard circumvention.
8.	Acting quickly to remove products that fall off without interrupting production.
9.	Safeguards in place slow down the work process and production.
10.	Bypassing increases downtime due to production disturbances.
11.	A safeguard is an obstruction to quickening the pace of work and enhancing productivity.
12.	A safeguard is bypassed to obtain greater precision.
13.	Safeguards are bypassed to save time carrying out the operations.
14.	There is time pressure to perform the job or to meet expectations.
15.	Bypassing occurs because of financial pressures.
16.	The time costs due to a program restart are reduced.
17.	Profitability diminishes if the customer’s order is not met.

A.4.3.3 Behavior

The behavior category comprises the incentives linked to intentional, unsafe acts, or certain situations in which the mind decides to behave in this way; for instance, it could be a worker’s habit, a worker underestimates the risk of bypassing, there is a lack of knowledge about the hazards of bypassing.

Table A. 3 Incentives to bypass safeguards related to the behavior category

NO.	Incentives to bypass
1.	Operators are inexperienced.
2.	Operators feel machines are safe without safeguards, and using them is unnecessary.
3.	There is a lack of knowledge on the hazards, the severity of consequences or the risks due to the defeating of safeguards.
4.	The risk of bypassing is underestimated or overlooked.
5.	Operators do not know that using a safeguard is required.
6.	Operators forget to use the safeguard.
7.	Operators think that they used the safeguard.
8.	Operators cannot explain why they do not use a safeguard.
9.	Bypassing is a habit.
10.	Bypassing occurs with experienced operators because they think that they are less at risk than others.
11.	Safeguards are not checked before operating the machine to ensure that they are in place.
12.	Taking a risk is exciting for employees.

A.4.3.4 Machines or safeguarding

This category includes incentives related to the features, characteristics and functions of the machinery and tools applied to perform the job, such as impractical safeguards, accessibility to keys or tools for defeating, and safeguards with poor reliability.

Table A. 4 Incentives to bypass safeguards related to the machine or safeguarding category

NO.	Incentives to bypass
1.	Poor reliability of safeguards and their failures (e.g. false alarms, trips, and restarts) disturb the people and operations in the work area and stimulate a tendency to bypass.
2.	Safeguards can be disabled easily and with little effort.
3.	The required tools or keys for defeating are accessible in enterprises.
4.	Producing unusual pieces of work requires a safeguard defeat.
5.	Safeguards are difficult to use because they are impractical.
6.	An unsuitable safeguard has been selected in the design phase, which is unacceptable for the operator.
7.	Easy access to software and switches make safeguards possible to defeat.
8.	Safeguards are not maintained correctly to ensure complete protection.
9.	There is an unsuitable machine to work with.
10.	A safeguard vibrates or rattles.
11.	The machine design is poor.
12.	There is a lack of flexibility in programming (e.g. a program that goes back to the beginning when the machine was stopped for swarf removal, etc., and it cannot be restarted mid-cycle or when the safeguard has to be enabled all the time or just during CNC mode.)

Table A. 4 Incentives to bypass safeguards related to the machine or safeguarding category (continued)

NO.	Incentives to bypass
13.	The regulatory requirements do not clarify whether safeguards should be operated all the time or just when operating in CNC mode.
14.	Machines are produced by manufacturers with poor quality safeguards.
15.	Moving the heavy safeguard is difficult.
16.	The safeguard's size makes it difficult to access areas around it.
17.	Clothing is caught or cuts happen because of the physical characteristics of a safeguard.

A.4.3.5 Corporate climate

This category encompasses incentives linked to individual perceptions of the work environment that influence individual motivation and attitude. A lack of commitment by management, lack of worker involvement, and a lack of adequate training about manipulation are some examples of incentives to bypass related to the corporate climate category.

Table A. 5 Incentives to bypass safeguards related to the corporate climate category

NO.	Incentives to bypass
1.	Operators behave as though they are experienced.
2.	Other individuals are involved, not just operators.
3.	There is a lack of management commitment and managers ordered, tolerated, encouraged or ignored circumvention.
4.	There are no enforcement or disciplinary actions for those who bypass safeguards.
5.	There is a lack of adequate training and awareness about manipulation.
6.	Bypassing a safeguard is not detectable; they are usually restored or bosses cannot detect it.
7.	Employee involvement is ignored when procuring machines or other OHS issues.
8.	Experienced operators force others to bypass, or defeating is carried out with peers.
9.	Bypassing occurs to achieve encouragement and performance bonuses from bosses.
10.	There is no supervision that monitors if a safeguard is enabled.
11.	The issue of defeating is not integrated into a culture of safety.
12.	Current policies and procedures are inadequate.

A.5 Discussion

Prerequisites for the development of the holistic assessment tool have been presented that enable the enterprises, as users of the machines, to estimate the probability of bypassing in their workplace. The main findings of this study are discussed in the following:

- The incentive to bypass is one of the parameters to consider in the new assessment tool, not only to address the incentives related to the machine and safeguarding, but also to encompass incentives associated with ergonomics, productivity, behavior and corporate climate, which contrasts with existing tools. Therefore, this advantage makes the assessment tool that would be developed in our next research more comprehensive than the tools that have been suggested in previous studies.
- Four levels are considered in the probability of bypassing to attain more precise results for prioritization, as per Chinniah et al. (2011), who proposed at least four levels of risk to avoid overestimating risks. As such, three and five levels of parameters are compatible with most risk estimation tools.
- The probability level ranking helps decision makers in enterprises prioritize corrective actions to reduce and eliminate bypassing guards and protective devices. Therefore, enterprises will experience continuous improvement to change their current workplace conditions and to provide a safer workplace for their employees with minimum incentives for defeating.
- According to the findings of Haghighi, Chinniah, et al. (2019) related to the 82 preventive measures, we calculated the frequency of solutions dedicated to every phase and every influential factor presented in Table A. 6. That information demonstrates more diversity of the preventive solutions in the usage phase by considering organizational factors (e.g., training, supervision).

Table A. 6 Frequency of solutions to prevent bypassing in various phases and influence factors

		Phases		
		Design	Manufacturing	Usage
Influential factors	Technical	30	13	3
	Organizational	-	-	32
	Individual	-	-	4

Therefore, by considering a comprehensive scope of incentives to bypass, this helps enterprises - as the machine’s users - search for incentives for defeating among the various aspects of their work environment. The latter would be more than just focusing on machine and safeguarding modifications to prevent bypassing, which was considered in two other phases (i.e. the design and machine manufacturing phases). Consequently, the tool is meant for the usage phase, in contrast to tools from previous research studies that were meant for the design and manufacturing phases (the IFA assessment matrix or the DGUV checklist). Companies, as the machine's users, should be able to identify the existing incentives more accurately among the different categories considered in the tool. Subsequently, they should be able to select more suitable preventive measures from the technical, organizational, and individual influencing factors in order to better promote the use of guards and protective devices.

A.6 Conclusions

Bypassing safeguards can have harmful consequences for individuals and organizations. This paper provides the foundation to develop a holistic assessment tool in our next research work, which will estimate the probability of bypassing. To achieve this, three prerequisites are considered in order to design the new assessment tool. One of the inputs encompasses a comprehensive scope of incentives in ergonomics, productivity, behavior, machine or safeguarding and corporate climate based on Haghighi, Chinniah, et al. (2019). The logic and the structure of the new assessment tool are adapted from the assessment matrix developed by IFA (2011) for designers. Considering 72 incentives in the above-mentioned five categories for designing the new tool makes the latter more comprehensive than the IFA assessment matrix.

Afterwards, the OHS-related risk estimation tools are studied in order to sufficiently identify the influencing parameters and the number of levels for parameters and risk. "The situation of bypassing" and "effect level of incentives to bypass" at an enterprise were two parameters used to estimate the probability of bypassing. According to the number of levels for the parameters and the risk proposed by Chinniah et al. (2011), three levels are taken into account for the aforementioned parameters. Four levels are considered in the probability of bypassing, while the number of levels for the incentives to bypass in the IFA assessment matrix was three levels. This takes into consideration that the optimal number of levels would make the new assessment tool more compatible with the majority of risk estimation tools and create a reduction in variability during the estimation.

The aim of the holistic assessment tool that would be realized in future research is to assess the existing incentives to bypass in enterprises and to determine the probability level of bypassing in order to prioritize preventive actions. Eventually, the usability of the new tool would be validated as well. Therefore, the findings of this paper serve the required inputs for building such a tool in the machinery use phase.

A.7 Acknowledgment

We would like to thank NSERC for the financial support.

APPENDIX B – DETAILED INFORMATION RELATED TO THE SCENARIOS

B.1 Scenario W: bypassing safeguards on a circular knitting machine

Table B. 1 describes the summary of an accident related to bypassing involving a circular knitting machine.

Table B. 1 Scenario W- Summary of a bypassing practice (CNESST, 1990)

Manufacturing sector	Textile company
Machine	Circular knitting machine
Existing safeguards	The interlocking guards are locked by an electrical mechanism at a mechanical double action button that prevents operation if the guards are not locked.
Activity	There was a problem with the fabric on the spinner of the machine. The material had twisted. The worker entered the dangerous zone and cut the fabric with scissors to solve the problem.
The method of bypassing	A piece of metal was inserted between the “start” button and the frame that kept the machine in operation to avoid pushing the “start” button every time that a problem was solved. Therefore, the machine restarted automatically, as soon as the operator corrected the fault. In reality, the mechanical locking system for the guard had been neutralized.
Flaws from the accident report identified as incentives to bypass	(a) The locking system of the guard was bypassed to fix the problem. (b) The absence of supervision and periodic inspections. (c) The absence of safety instructions. (d) It was generally accepted by both the employer and the workers to use ways to neutralize the starting

	mechanism. (e) It was a common practice to operate the circular knitting machine by disabling the locking mechanism. (f) The operator ignored the consequences of the neutralization.
Consequence	Death due to being trapped (being jammed) between the frame of the knitting machine and the spinner.

The corresponding incentives are marked in Table B. 2.

Table B. 2 Selection of corresponding incentives in the tool for the flaws in scenario W

Flaws extracted from the accident report	**Incentive code * - The corresponding incentives in the proposed tool - Effect level**
(a)	I19- Safeguard removal is necessary to perform activities such as adjustments, troubleshooting, maintenance, and installation (no specific operation modes exist for performing them) (+)
(b)	I60- There is no supervision that monitors if a safeguard is enabled (+)
(c)	I64- Current policies and procedures are inadequate (++)
(d)	I36- There is a lack of management commitment and managers ordered, tolerated, encouraged or ignored circumvention (++)
(e)	I63- The issue of defeating is not integrated into a culture of safety (++) I46- Bypassing is a habit (++)
(f)	I8- The risk of bypassing is underestimated or overlooked (++)

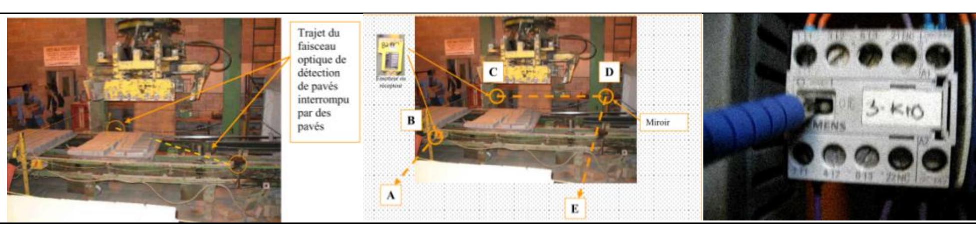
*The code of an incentive comes from Appendix C.

Figure B. 1 illustrates the identification of the incentives to bypass and the probability of bypassing estimated for troubleshooting activity on circular knitting machine in scenario W.

B.2 Scenario X: bypassing safeguards on a palletizing system

Table B. 3 describes the summary of an accident related to bypassing involving a palletizing system.

Table B. 3 Scenario X- Summary of a bypassing practice (CNESST, 2006)



Manufacturing sector	Concrete products manufacturing
Machine	Palletizing system (palletizer and its gripper)

Existing safeguards	- Safety light beam in the pick-up station - Pressure-sensitive mat in the storing station
Activity	During palletizing operations in automatic mode, the operator bended under the gripper to remove a row of the paving blocks which was an extra row. The safety light beam was neutralized and it did not detect the presence of the operator in the protected area by the safety light beam.
The method of bypassing	A pen cap was pushed into (wedged) the lever of the relay which controls the function of the safety light beam system.
Flaws from the accident report identified as incentives to bypass	(a) A dangerous procedure was used to remove a row of paving blocks on the plate positioned under the gripper. There is no safe working method for fault correction when palletizing. (b) The operator ignores the danger to which he is exposed because of the lack of training. There is no structured training plan for palletizing operators as well as their substitutes in terms of machine safety. (c) There is no program for periodic inspections of workplaces and supervision measures to understand that the safety light beam is inoperative. (d) The emission of dust by the rotary brush at the conveyor interacts with the safety light beam system and causes unplanned stoppage of the palletization in automatic mode, which, in the opinion of an operator, caused the system to be neutralized. (e) The plant manager, night shift foreman and operators knew how to neutralize the safety light beam system. (f) The relay is in a cabinet that is accessible to all while it is not locked. (g) The relay is not a safety relay and it is easy to neutralize. (h) The foreman had found that the safety light beam system was disabled, but he did not take any corrective action. In addition, the employer was informed of the non-functioning of the safety light beam system. (i) The safety light curtain in another workshop of the company was neutralized as well.
Consequence	Death due to being crushed by the gripper of the palletizer.

The corresponding incentives are marked in Table B. 4.

Table B. 4 Selection of corresponding incentives in the tool for the flaws in scenario X

Flaws extracted from the accident report	Incentive code * - The corresponding incentives in the proposed tool - Effect level
(a)	I64- Current policies and procedures are inadequate (++) (for the safety light beam)
(b)	I51- There is a lack of adequate training and awareness about manipulation (++) (for all safeguards) I8- The risk of bypassing is underestimated or overlooked (+) (for the safety light beam)
(c)	I60- There is no supervision that monitors if a safeguard is enabled (++) (for all safeguards)
(d)	I16- Poor reliability of safeguards and their failures (e.g. false alarms, trips, and restarts) disturb the people and operations in the work area and stimulate a tendency to bypass (++) (for the safety light beam)
(e)	I17- Safeguards can be disabled easily and with little effort (++) (for the safety light beam) I29- Easy access to software and switches make safeguards possible to defeat (+)(for the safety light beam)
(f)	I29- Easy access to software and switches make safeguards possible to defeat (++)(for the safety light beam)
(g)	I17- Safeguards can be disabled easily and with little effort (++) (for the safety light beam)
(h)	I36- There is a lack of management commitment and managers ordered, tolerated, encouraged or ignored circumvention (++)(for all safeguards)
(i)	I46- Bypassing is a habit (+) (for all safeguards)

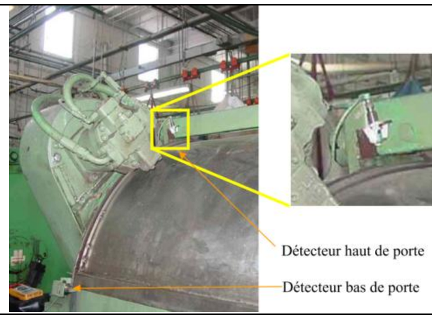
*The code of an incentive comes from Appendix C.

Figure B. 2 illustrates the identification of the incentives to bypass and the probability of bypassing estimated for palletizing operations on palletizing system in scenario X.

B.3 Scenario Z: bypassing safeguards on a horizontal washing machine

Table B. 5 describes the summary of an accident related to bypassing involving a horizontal washing machine.

Table B. 5 Scenario Z- Summary of a bypassing practice (CNESST, 2008)



Manufacturing sector	Renting and other laundry services
Machine	Horizontal washing machine
Existing safeguards	Proximity sensors: detection system that sends signals to the control module to indicate opening or closing of the door. The control module allows the rotation when the door of the tank is closed.
Activity	A worker enters a hazardous zone, which is a compartment of a washing machine, to inspect the condition of a steam diffuser.
The method of bypassing	The sensor at the bottom of the door is disconnected. A 25 ¢ coin is attached with the adhesive tape to the second sensor on the top of the tank door. Two different circuits are thus neutralized and the control module of the machine receives a signal indicating that the door is closed.
Flaws from the accident report identified as incentives to bypass	(a) The ease and simplicity of neutralizing the detector encourages maintenance workers to proceed in this manner. The risk level mentioned in the warnings should also provide a higher level of difficulty for defeating detectors. (b) The design of the detectors favored (helped) the ease and neutralization of the detectors. (c) No theoretical or practical training had been developed for maintenance workers. (d) The method used by Québec Linge includes the neutralization of two detectors and maintaining all energy sources which is not a safe method to access a danger zone. Maintenance personnel neutralize detection systems whenever a repair requires entry into the drum. (e) Maintenance personnel do not have the knowledge to perform safe repairs in a hazardous zone of the washing machine. The worker did not have sufficient knowledge to predict the operation while safety devices were disabled.
Consequence	The worker suffered multiple serious injuries.

The corresponding incentives are marked in Table B. 6.

Table B. 6 Selection of corresponding incentives in the tool for the flaws in scenario Z

Flaws extracted from the accident report	**Incentive code * - The corresponding incentives in the proposed tool - Effect level**
(a)	I17- Safeguards can be disabled easily and with little effort (++)
(b)	I55- The machine design is poor (++)
(c)	I51- There is a lack of adequate training and awareness about manipulation (++)
(d)	I64- Current policies and procedures are inadequate (++)
(e)	I7- There is a lack of knowledge on the hazards, the severity of consequences or the risks due to the defeating of safeguards (++)

*The code of an incentive comes from Appendix C.

Figure B. 3 illustrates the identification of the incentives to bypass and the probability of bypassing estimated for inspection activity on horizontal washing machine in scenario Z.

Machine: Circular knitting machine

Activity	Operation modes: Automatic	Operation modes: Manual	Operation modes: …	Existing Safeguard	How is the bypassing situation?	The incentives to bypass: Ergonomics			Productivity					Behavior							Machine or safeguarding			Corporate Climate							The probability level of bypassing for the activity
						I15	…	I71	I1	…	I19	…	I67	I5	…	I8	…	I46	…	I72	I16	…	I70	I12	I27	I36	…	I60	I63	I64	
						A safeguard reduces the visibility of the tools and activities such as working process, production, setting and so on.	…	Metabolic energy consumption will decrease by bypassing.	There is a lot of work to carry out.	…	Safeguard removal is necessary to perform activities such as adjustments, troubleshooting, maintenance, and installation (no specific operation modes exist for performing them).	…	Profitability diminishes if the customer's order is not met.	Operators are inexperienced.	…	The risk of bypassing is underestimated or overlooked.	…	Bypassing is a habit.	…	Taking a risk is exciting for employees.	Poor reliability of safeguards and their failures (e.g. false alarms, trips, and restarts) disturb the people and operations in the work area and stimulate a tendency to bypass.	…	Clothing is caught or cuts happen because of the physical characteristics of a safeguard.	Operators behave as though they are experienced.	Other individuals are involved, not just operators.	There is a lack of management commitment and managers ordered, tolerated, encouraged or ignored circumvention.	…	There is no supervision that monitors if a safeguard is enabled.	The issue of defeating is not integrated into a culture of safety.	Current policies and procedures are inadequate.	
Troubleshooting on the machinery		*		Interlocking guards with guard locking	A	0	0	0	0	0	+	0	0	0	0	++	0	++	0	0	0	0	0	0	0	++	0	+	++	++	High

Figure B. 1 The proposed assessment tool applied to scenario W

Machine: Palletizing system (palletizer and its gripper)

Activity	Operation modes: Automatic	Operation modes: Manual	Operation modes: …	Existing Safeguard	How is the bypassing situation?	The incentives to bypass: Ergonomics			Productivity			Behavior							Machine or safeguarding						Corporate Climate									The probability level of bypassing for the activity
						I15	…	I71	I1	…	I67	I5	…	I8	…	I46	…	I72	I16	I17	…	I29	…	I70	I12	I27	I36	…	I51	…	I60	I63	I64	
						A safeguard reduces the visibility of the tools and activities such as working process, production, setting and so on.	…	Metabolic energy consumption will decrease by bypassing.	There is a lot of work to carry out.	…	Profitability diminishes if the customer's order is not met.	Operators are inexperienced.	…	The risk of bypassing is underestimated or overlooked.	…	Bypassing is a habit.	…	Taking a risk is exciting for employees.	Poor reliability of safeguards and their failures (e.g. false alarms, trips, and restarts) disturb the people and operations in the work area and stimulate a tendency to bypass.	Safeguards can be disabled easily and with little effort.	…	Easy access to software and switches make safeguards possible to defeat.	…	Clothing is caught or cuts happen because of the physical characteristics of a safeguard.	Operators behave as though they are experienced.	Other individuals are involved, not just operators.	There is a lack of management commitment and managers ordered, tolerated, encouraged or ignored circumvention.	…	There is a lack of adequate training and awareness about manipulation.	…	There is no supervision that monitors if a safeguard is enabled.	The issue of defeating is not integrated into a culture of safety.	Current policies and procedures are inadequate.	
Palletizing operations	*			Safety light beam	A	0	0	0	0	0	0	0	0	+	0	+	0	0	++	++	0	++	0	0	0	0	++	0	++	0	++	0	++	High
	*			Pressure-sensitive mat	B	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	0	0	0	0	0	++	0	++	0	++	0	0	Moderate

Figure B. 2 The proposed assessment tool applied to scenario X

Machine: Horizontal washing machine

	Operation modes					The incentives to bypass																						
						Ergonomics			Productivity			Behavior					Machine or safeguarding						Corporate Climate					
						I15	…	I71	I1	…	I67	I5	…	I7	…	I72	I16	I17	…	I55	…	I70	I12	…	I51	…	I64	
Activity	**Automatic**	**Manual**	**…**	**Existing Safeguard**	**How is the bypassing situation?**	A safeguard reduces the visibility of the tools and activities such as working process, production, setting and so on.	…	Metabolic energy consumption will decrease by bypassing.	There is a lot of work to carry out.	…	Profitability diminishes if the customer's order is not met.	Operators are inexperienced.	…	There is a lack of knowledge on the hazards, the severity of consequences or the risks due to the defeating of safeguards	…	Taking a risk is exciting for employees.	Poor reliability of safeguards and their failures (e.g. false alarms, trips, and restarts) disturb the people and operations in the work area and stimulate a tendency to bypass.	Safeguards can be disabled easily and with little effort.	…	The machine design is poor.	…	Clothing is caught or cuts happen because of the physical characteristics of a safeguard.	Operators behave as though they are experienced.	…	There is a lack of adequate training and awareness about manipulation.	…	Current policies and procedures are inadequate.	**The probability level of bypassing for the activity**
Inspection a part of machine		*		Proximity sensors	A	0	0	0	0	0	0	0	0	++	0	0	0	++	0	++	0	0	0	0	++	0	++	**High**

Figure B. 3 The proposed assessment tool applied to scenario Z

APPENDIX C – LIST OF THE INCENTIVES PER CATEGORY FROM (HAGHIGHI, CHINNIAH, ET AL., 2019) APPLIED TO THE HOLISTIC ASSESSMENT TOOL

Category	Code	Description
Ergonomics	I15	A safeguard reduces the visibility of the tools and activities such as working process, production, setting and so on.
	I21	Removing and installing safeguards frequently for lubrication is tedious.
	I24	Bypassing provides convenience and facilitates work.
	I31	A safeguard limits the adequate lighting in a workplace.
	I34	Machinery and safeguards are not user friendly and have poor ergonomics.
	I35	There is not enough workspace when using a safeguard.
	I39	Safeguard is bypassed to have better audibility.
	I40	Safeguard is bypassed to require less physical effort.
	I41	Safeguard is bypassed to reduce the rate of travel.
	I42	Safeguard is bypassed to facilitate movement.
	I43	Safeguard is bypassed to improve the flow of movement.
	I47	Safeguard is bypassed because of stress.
	I58	There is impaired accessibility to the job and the tools.
	I71	Metabolic energy consumption will decrease by bypassing.
Productivity	I1	There is a lot of work to carry out.
	I2	Reaching into a hazardous zone several times to do the work.
	I3	Using safeguards is extra work.
	I4	Using safeguards is time-consuming.
	I14	Safeguards disturb the work process and production.
	I19	Safeguard removal is necessary to perform activities such as adjustments, troubleshooting, maintenance, and installation (no specific operation modes exist for performing them).
	I20	Coping with faults would be more efficient with safeguard circumvention.
	I22	Acting quickly to remove products that fall off without interrupting production.
	I25	Safeguards in place slow down the work process and production.
	I32	Bypassing increases downtime due to production disturbances.
	I33	A safeguard is an obstruction to quickening the pace of work and enhancing productivity.
	I38	A safeguard is bypassed to obtain greater precision.
	I44	Safeguards are bypassed to save time carrying out the operations.
	I50	There is time pressure to perform the job or to meet expectations.
	I61	Bypassing occurs because of financial pressures.
	I65	The time costs due to a program restart are reduced.
	I67	Profitability diminishes if the customer’s order is not met.
Behavior	I5	Operators are inexperienced.

Category	Code	Description
	I6	Operators feel machines are safe without safeguards, and using them is unnecessary.
	I7	There is a lack of knowledge on the hazards, the severity of consequences or the risks due to the defeating of safeguards.
	I8	The risk of bypassing is underestimated or overlooked.
	I9	Operators do not know that using a safeguard is required.
	I10	Operators forget to use the safeguard.
	I11	Operators think that they used the safeguard.
	I13	Operators cannot explain why they do not use a safeguard.
	I46	Bypassing is a habit.
	I49	Bypassing occurs with experienced operators because they think that they are less at risk than others.
	I62	Safeguards are not checked before operating the machine to ensure that they are in place.
	I72	Taking a risk is exciting for employees.
Machine or safeguarding	I16	Poor reliability of safeguards and their failures (e.g. false alarms, trips, and restarts) disturb the people and operations in the work area and stimulate a tendency to bypass.
	I17	Safeguards can be disabled easily and with little effort.
	I18	The required tools or keys for defeating are accessible in enterprises.
	I23	Producing unusual pieces of work requires a safeguard defeat.
	I26	Safeguards are difficult to use because they are impractical.
	I28	An unsuitable safeguard has been selected at the design phase, which is unacceptable for the operator.
	I29	Easy access to software and switches make safeguards possible to defeat.
	I30	Safeguards are not maintained correctly to ensure complete protection.
	I45	There is an unsuitable machine to work with.
	I48	A safeguard vibrates or rattles.
	I55	The machine design is poor.
	I56	There is a lack of flexibility in programming (e.g. a program that goes back to the beginning when the machine was stopped for swarf removal, etc., and it cannot be restarted mid-cycle or when the safeguard has to be enabled all the time or just during CNC mode.)
	I57	The regulatory requirements do not clarify whether safeguards should be operated all the time or just when operating in CNC mode.
	I66	Machines are produced by manufacturers with poor quality safeguards.
	I68	Moving the heavy safeguard is difficult.
	I69	The safeguard’s size makes it difficult to access areas around it.
	I70	Clothing is caught or cuts happen because of the physical characteristics of a safeguard.
Corporate climate	I12	Operators behave as though they are experienced.
	I27	Other individuals are involved, not just operators.

Category	Code	Description
	I36	There is a lack of management commitment and managers ordered, tolerated, encouraged or ignored circumvention.
	I37	There are no enforcement or disciplinary actions for those who bypass safeguards.
	I51	There is a lack of adequate training and awareness about manipulation.
	I52	Bypassing a safeguard is not detectable; they are usually restored or bosses cannot detect it.
	I53	Employee involvement is ignored when procuring machines or other OHS issues.
	I54	Experienced operators force others to bypass, or defeating is carried out with peers.
	I59	Bypassing occurs to achieve encouragement and performance bonuses from bosses.
	I60	There is no supervision that monitors if a safeguard is enabled.
	I63	The issue of defeating is not integrated into a culture of safety.
	I64	Current policies and procedures are inadequate.

APPENDIX D –DETAILED EXPALNATION OF THE FORMULA PRESENTED IN FIGURE 5.3

This appendix is not a part of the second article (presented in Chapter 5) that was officially published. It has only been added to this thesis for further clarification.

In this appendix, the entire process of defining the formula presented in Figure 5.3 is explained. This formula derives from that of IFA (2011) presented and described in Section 3.2.2. IFA's formula leads to three possible levels to evaluate the incentive to bypass (ITB). On the contrary, the formula in Figure 5.3 automatically calculates four probability levels of bypassing in the Excel spreadsheet by taking into consideration the holistic approach of the tool. In the following, the functions used in the formula in Figure 5.3 are explained as defined in Excel:

1- IF: Checks whether a condition is met, and returns one value if TRUE, and another value if FALSE.
2- COUNTA: Counts the number of cells in a range that are not empty.
3- COUNT: Counts the number of cells in a range that contains numbers.
4- COUNTIF: Counts the number of cells within a range that meet the given condition.

The above-mentioned functions and the other elements of the formula help translate the descriptions of four levels of bypassing probability presented in Table 5.4 into an Excel spreadsheet.

The first part of this formula, including "IF(AND(COUNTA(A1:C1)>0,D1<>""")," makes sure that the initial data related to the "Operation modes" and "Existing safeguards" are entered in order to have complete knowledge about the machine to begin the assessment.

The rest of the formula uses a combination of five IF functions to distinguish four levels of bypassing probability. The conditions were defined based on the answers to the question, "How is the bypassing situation?" including A, B, and C, as well as the effect levels of identified incentives to bypass including 0, +, and ++. The first and second IF function, respectively, estimate the low and moderate levels of bypassing probability. The third IF function, along with the fourth IF function that calculates the number of identified incentives, as well as along with the fifth IF function, which calculates whether the number of identified incentives with a significant effect (++) is half or more than half of the identified incentives, estimate the high level of bypassing probability. If the fifth IF function is not met, the significant level of bypassing probability is estimated.

APPENDIX E – THE INCENTIVE CODES AND DESCRIPTIONS OF CODES FROM (HAGHIGHI, CHINNIAH, ET AL., 2019) APPLIED TO THE ACCIDENT REPORTS IN THIS PAPER

Incentive code	Description of the code	Category*
I2	Reaching into a hazardous zone several times to do the work.	P
I7	There is a lack of knowledge on the hazards, the severity of consequences or the risks due to the defeating of safeguards.	B
I8	The risk of bypassing is underestimated or overlooked.	B
I14	Safeguards disturb the work process and production.	P
I16	Poor reliability of safeguards and their failures (e.g. false alarms, trips, and restarts) disturb the people and operations in the work area and stimulate a tendency to bypass.	M
I17	Safeguards can be disabled easily and with little effort.	M
I19	Safeguard removal is necessary to perform activities such as adjustments, troubleshooting, maintenance, and installation (no specific operation modes exist for performing them).	P
I26	Safeguards are difficult to use because they are impractical.	M
I28	An unsuitable safeguard has been selected at the design phase, which is unacceptable for the operator.	M
I29	Easy access to software and switches make safeguards possible to defeat.	M
I36	There is a lack of management commitment and managers ordered, tolerated, encouraged or ignored circumvention.	C
I37	There are no enforcement or disciplinary actions for those who bypass safeguards.	C
I46	Bypassing is a habit.	B
I51	There is a lack of adequate training and awareness about manipulation.	C
I53	Employee involvement is ignored when procuring machines or other OHS issues.	C
I55	The machine design is poor.	M
I58	There is impaired accessibility to the job and the tools.	E
I60	There is no supervision that monitors if a safeguard is enabled.	C
I63	The issue of defeating is not integrated into a culture of safety.	C
I64	Current policies and procedures are inadequate.	C

APPENDIX F – THE FORMER PROPOSED ISO 14119-INSPIRED TOOL TO PREVENT BYPASSING SAFEGUARDS ON INDUSTRIAL MACHINES

Machine:

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
		Operation modes					The incentives to bypass															
							Ergonomics			Productivity			Behavior			Machine or safeguarding			Corporate Climate			
							I15	...	I71	I1	...	I67	I5	...	I72	I16	...	I70	I12	...	I64	
	Activity	**Automatic**	**Manual**	**...**	**Existing Safeguard**	**How is the bypassing situation?**	A safeguard reduces the visibility of the tools and activities such as working process, production, setting and so on.	...	Metabolic energy consumption will decrease by bypassing.	There is a lot of work to carry out.	...	Profitability diminishes if the customer's order is not met.	Operators are inexperienced.	...	Taking a risk is exciting for employees.	Poor reliability of safeguards and their failures (e.g. false alarms, trips, and restarts) disturb the people and operations in the work area and stimulate a tendency to bypass.	...	Clothing is caught or cuts happen because of the physical characteristics of a safeguard.	Operators behave as though they are experienced.	...	Current policies and procedures are inadequate.	**The probability level of bypassing for the activity**
1																						
2																						
3																						
4																						
5																						
6																						
7																						
8																						
9																						
10																						

APPENDIX G – THE QUESTIONNAIRE FOR RECEIVING THE OCCUPATIONAL HEALTH AND SAFETY (OHS) PRACTITIONERS' FEEDBACK

<table>
<tr><th colspan="2">Questionnaire-OHS practitioner's opinions</th></tr>
<tr><th colspan="2">Company Information</th></tr>
<tr><td>Company Name:</td><td>Sector:</td></tr>
<tr><td>Number of employees:</td><td>Type of production/services:</td></tr>
<tr><td colspan="2">Address:</td></tr>
<tr><th colspan="2">Contact person (OHS practitioner)</th></tr>
<tr><td>Name:</td><td>Position:</td></tr>
<tr><td>Experience in the position (year):</td><td>Date of completion:</td></tr>
<tr><td rowspan="3">While using the tool</td><td>1- Is the list of incentives in the tool satisfying? ☐Yes ☐No
Explain:…………………………………………………………………………..
……………………………………………………………………………...</td></tr>
<tr><td>2- Is the tool easy to use (user-friendly)? ☐Yes ☐No
Explain:…………………………………………………………………………..
……………………………………………………………………………...</td></tr>
<tr><td>3- Is the tool useful to identify the incentives to bypass in the company? ☐Yes ☐No
Explain:…………………………………………………………………………..
……………………………………………………………………………...</td></tr>
<tr><td rowspan="3">The results of the tool</td><td>1- Is the tool appropriate to estimate the probability of bypassing in the company? ☐Yes ☐No
Explain:…………………………………………………………………………..
……………………………………………………………………………...</td></tr>
<tr><td>2- Are the probability levels of bypassing accurate based on the work environment of the company? ☐Yes ☐No
Explain:…………………………………………………………………………..
……………………………………………………………………………...</td></tr>
<tr><td>3- Is the tool useful to prevent bypassing? ☐Yes ☐No
Explain:…………………………………………………………………………..
……………………………………………………………………………...</td></tr>
<tr><td colspan="2">Limitations of the tool:</td></tr>
<tr><td colspan="2">Other comments:</td></tr>
<tr><td colspan="2">Signature -- Date -----------</td></tr>
</table>

APPENDIX H – THE EXISTING INCENTIVES TO BYPASS IDENTIFIED FOR EVERY SAFEGUARD AND ITS PROBABILITY LEVEL OF BYPASSING OBTAINED FROM APPLYING THE TOOL TO CASE STUDIES

Company	Machine	Activity	Operation Modes[1]	Existing Safeguard	Answer to Question	The Incentives to BYPASS[2, 3]	The Probability Level of Bypassing for the Activity
A	Bagger	Adjustment of the conveyor speed	Man.	Interlocking access gate	A	I24- I40- I41- I43- I58- I2- I3- I4- I19- I38- I44- I50- I61- I67- I46- I18- I36- I64	High
	Robot cell	Teach programming of the robot in the manual mode	Auto	Emergency stop safety function triggered by enclosure opening or E-stop button	A	I24- I1- I3- I4- I25- I32- I33- I44- I50- I61- I67- I46- I17- I18- I36- I52	High
	Drill press	Machining	Auto	Chuck guard	B	I15- I21- I20- I50- I5- I18- I12- I27- I52	Moderate
	Conventional lathe machine	Machining	Man.	Interlocking removable guard (protection against projection: protection against fluid and falling metals)	A	I15- I24- I34- I47- I1- I19- I20- I22- I25- I50- I18- I23	Significant

Company	Machine	Activity	Operation Modes[1]	Existing Safeguard	Answer to Question	The Incentives to BYPASS[2, 3]	The Probability Level of Bypassing for the Activity
				Interlocking movable chuck guard	B	I24- I47- I1- I19- I20- I50- I18	Moderate
				Protective curtain (screw bearing protection)	B	I18	Moderate
				Interlocking movable guard (protection of the other team members against projection of fluid or falling of metals)	C	-	Low
		Cleaning	Man.	Interlocking removable access guard (access to the back of the machine)	B	I18	Moderate
	Grinding machine	Grinding	Man.	Removable guard (protection against sparks)	B	I15- I43- I47- I1- I20- I17- I18- I57	Moderate
		Brushing	Man.	Movable guard (protection	B	I43- I47- I1- I20- I17- I18- I57	Moderate

Company	Machine	Activity	Operation Modes[1]	Existing Safeguard	Answer to Question	The Incentives to BYPASS[2, 3]	The Probability Level of Bypassing for the Activity
				against projection)			
B	Wire drawing machine	Pulling a new wire from the crown to the finishing block or replacing the matrices (dye)	Auto	Interlocking guard	B	I24- I31- I58- I3- I4- I14- I19- I20- I25- I33- I50- I5- I6- I7- I8- I9- I10- I49- I18- I29- I55- I70- I12- I51- I52- I53- I54- I60- I64	Moderate
		Inspecting the wire being drawn	Auto	Interlocking guard	B	I15- I24- I40- I42- I71- I3- I19- I20- I50- I5- I6- I8- I10- I49- I62- I17- I18- I29- I12- I36- I37- I51- I52- I53	Moderate
		Welding and grinding the wire ends of the 2 crowns while the wire drawing machine is running	Man.	Interlocking guard	B	I15- I40- I47- I3-I50- I5- I6- I8- I10- I13- I49- I62- I17- I18- I12- I36- I37- I51- I52- I53	Moderate
		Disassembly, adjustment or cleaning of the wire drawing machine in interlocking guard sections	Man.	Interlocking guard	A	I15- I21- I71- I2- I3- I14- I19- I20- I25- I33- I44- I50- I6- I8- I10- I49- I62- I17- I18- I28- I29- I55- I69- I12- I36- I37- I51- I52- I53	Significant
	Galvanizing lead bath	Passing the wire in the lead bath	Man.	Removable guard	A	I24- I31- I35- I42-I43- I58- I71- I2- I3- I14- I19- I20- I25- I33- I44-	Significant

Company	Machine	Activity	Operation Modes[1]	Existing Safeguard	Answer to Question	The Incentives to BYPASS[2, 3]	The Probability Level of Bypassing for the Activity
						I65- I67- I6- I7- I8- I46- I49- I62- I17- I30- I55- I12- I27- I36- I37- I54	
	Strander	Monitoring from outside the enclosure while the equipment is running	Auto	Interlocking guard	C	-	Low
	Hydraulic press	Pressing the parts	Man.	Protection rods	A	I15- I24- I43- I58- I71- I3- I19- I22- I44- I67- I6- I7- I8- I9- I10- I46- I62- I17- I18- I23- I36- I37- I51- I60	Significant
C	Discharge conveyor	Unjamming	Auto or Man.	Enclosure with interlocking key in the control panel	A	I15- I24- I31- I34- I40- I42- I43- I58- I71- I1- I2- I3- I4- I14- I22- I25- I32- I33- I44- I50- I65- I67- I6- I7- I8- I46- I49- I62- I17- I18- I26- I28- I55- I66- I69- I70- I12- I27- I36- I37- I51- I52- I60 - I63- I64	High
		Preventive maintenance	Man.	Enclosure with interlocking key in the control panel	B	I15- I31- I34- I39- I42- I58- I71- I1- I3- I19- I38- I67- I7- I8- I62- I17- I18- I57- I69- I12- I27- I36- I37- I51- I52- I60- I63- I64	Moderate
		Weekly cleaning	Man.	Enclosure with interlocking key in the control panel	B	I34- I58- I1- I2- I3- I25- I33- I5- I7- I8- I62- I17- I18- I57- I69- I12- I36- I37- I51- I52- I63- I64	Moderate

Company	Machine	Activity	Operation Modes[1]	Existing Safeguard	Answer to Question	The Incentives to BYPASS[2, 3]	The Probability Level of Bypassing for the Activity
	Megabale press	Access on the top of the machine for inspection / troubleshooting in operation	Auto or Man.	Interlocking key in the control panel	A	I15- I24- I31- I34- I39- I40- I42- I43- I58- I71- I1- I2- I3- I4- I14- I19- I20- I25- I32- I33- I38- I44- I50- I67- I6- I7- I8- I46- I49- I62- I17- I18- I26- I28- I55- I57- I69- I12- I27- I36- I37- I51- I52- I53- I60- I63- I64	High
				Fence	B	I12- I27- I36- I37- I51- I52- I60- I63- I64	Moderate
		Operation	Auto or Semi	Light curtain to avoid entering the area where the operator must put the bags	B	I15- I71- I2- I3- I14- I20- I32- I33- I67- I7- I62- I17- I57- I12- I27- I36- I37- I51- I52- I60- I63- I64	Moderate
		Preventive maintenance	Auto or Man. or Semi	Light curtain to avoid entering the area where the operator must put the bags	B	I15- I24- I31- I39- I58- I71- I2- I3- I4- I19- I20- I25- I32- I33- I38- I44- I6- I7- I8- I46- I49- I62- I17- I18- I26- I28- I45- I55- I57- I69- I12- I27- I36- I37- I51- I52- I53- I60- I63- I64	Moderate
				Interlocking key in the control panel	B	I15- I24- I31- I39- I58- I71- I2- I3- I4- I19- I20- I25- I32- I33- I38- I44- I6- I7- I8- I46- I49- I62- I17- I18- I26- I28- I45- I55- I57- I69- I12- I27- I36- I37- I51- I52- I53- I60- I63- I64	Moderate

Company	Machine	Activity	Operation Modes[1]	Existing Safeguard	Answer to Question	The Incentives to BYPASS[2, 3]	The Probability Level of Bypassing for the Activity
				Fence	B	I12- I27- I36- I37- I51- I52- I60- I63- I64	Moderate
	Floor conveyor	Recycling good product from rejected bags	Auto	Interlocking enclosure	A	I15- I24- I31- I34- I35- I40- I42- I43- I58- I71- I1- I2- I3- I4- I14- I22- I25- I33- I44- I67- I6- I7- I8- I46- I62- I17- I18- I26- I28- I55- I57- I12- I36- I37- I51- I52- I53- I60- I63- I64	High
		Continuous operation	Auto or Man.	Fence	B	I15- I24- I31- I40- I42- I43- I71- I3- I44- I67- I7- I8- I46- I49- I62- I17- I18- I57- I12- I36- I37- I51- I52- I53- I60- I63- I64	Moderate
		Preventive maintenance	Man.	Guard	A	I15- I24- I34- I35- I58- I3- I19- I20- I38- I44- I67- I8- I46- I49- I62- I17- I18- I26- I57- I12- I27- I36- I37- I51- I52- I53- I60- I63- I64	Significant
	Wrapping machine	Wrapping two bags with plastic	Auto or Man.	Light curtain	A	I15- I24- I31- I35- I42- I43- I58- I71- I1- I2- I3- I14- I19- I20- I25- I32- I33- I38- I44- I67- I6- I7- I8- I46- I62- I17- I18- I26- I28- I29- I57- I69- I12- I36- I37- I51- I52- I53- I60- I63- I64	High
		Cleaning	Man.	Light curtain	B	I5- I6- I7- I8- I11- I46- I49- I62- I17- I18- I57- I12- I27- I36- I37- I51- I52- I53- I60- I63- I64	Moderate
		Preventive	Man.	Light curtain	B	I31- I58- I2- I19- I20- I38- I8- I46- I49- I62- I17- I18- I57- I69- I12-	Moderate

Company	Machine	Activity	Operation Modes[1]	Existing Safeguard	Answer to Question	The Incentives to BYPASS[2, 3]	The Probability Level of Bypassing for the Activity
		maintenance				I27- I36- I37- I51- I52- I53- I60- I63- I64	
	Small bag press	Troubleshooting of pneumatic system	Man.	Gate with Interlocking key in the control panel	A	I15- I24- I39- I42- I43- I58- I71- I1- I2- I3- I4- I14- I19- I20- I25- I32- I33- I38- I44- I67- I6- I7- I8- I46- I62- I17- I18- I26- I28- I29- I57- I69- I70- I12- I36- I37- I51- I52- I53- I60- I63- I64	High
				Fence	B	I12- I27- I36- I37- I51- I52- I60- I63- I64	Moderate
		Daily maintenance (door greasing, minor adjustments, changing Teflon on the sealer)	Auto or Man. or Semi	Gate with Interlocking key in the control panel	B	I24- I31- I39- I40- I58- I1- I2- I3- I14- I25- I32- I38- I44- I67- I8- I46- I49- I62- I17- I18- I56- I57- I69- I12- I27- I36- I37- I51- I52- I53- I60- I63- I64	Moderate
				Fence	B	I12- I27- I36- I37- I51- I52- I60- I63- I64	Moderate
		Normal operation	Auto	Gate with Interlocking key in the control panel	B	I58- I2- I3- I20- I22- I32- I67- I49- I62- I17- I18- I29- I56- I69- I12- I27- I36- I37- I51- I52- I53- I60- I63- I64	Moderate
				Fence	B	I12- I27- I36- I37- I51- I52- I60- I63- I64	Moderate
D	Coater #1	Adjustment of dyes	Man.	Movable guard	A	I15- I19- I22- I25- I32- I46- I17	Significant
		Troubleshooting of gas flame and	Man.	Fixed guard	A	I24- I19	Significant

Company	Machine	Activity	Operation Modes[1]	Existing Safeguard	Answer to Question	The Incentives to BYPASS[2, 3]	The Probability Level of Bypassing for the Activity
		camera					
		Troubleshooting of control box	Auto	Fixed guard	A	I24- I19	Significant
	Coater #2	Adjustment	Man.	Fixed guard	A	I24- I19	Significant
		Checking the belt	Man.	Fixed guard	A	I24- I19	Significant
		Fitting the switch	Man.	Fixed guard	A	I24- I19	Significant
	Winder	Adjustment of control valve	Man.	Fixed guard	A	I24- I19	Significant
	Lathe machine	Tool adjustment	Man.	Movable guard	A	I15- I24- I58- I19	Significant

[1] Man.= Manual, Auto= Automatic, Semi= semiautomatic. [2] The definitions for the codes of incentives are available in Appendix I and came from (Haghighi, Chinniah, et al., 2019). [3] Underlined font = incentive with significant effect (++), Normal font= incentive with slight effect (+)

APPENDIX I – DEFINITIONS OF THE INCENTIVE CODES FROM (HAGHIGHI, JOCELYN, ET AL., 2019A) WITH THE IMPROVED VERSION OF SOME BASED ON OHS PRACTITIONERS' FEEDBACK

Code of incentives	Definition
I1.	There is a lot of work to carry out.
I2.	Reaching into a hazardous zone several times to do the work.
I3.	Using safeguards is extra work.
I4.	Using safeguards is time-consuming.
I5.	Operators are inexperienced.
I6.	Operators feel machines are safe without safeguards, and using them is unnecessary.
I7.	There is a lack of knowledge on the hazards, the severity of consequences or the risks due to the defeating of safeguards.
I8.	The risk of bypassing is underestimated or overlooked.
I9.	Operators do not know that using a safeguard is required.
I10.	Operators forget to use the safeguard.
I11.	Operators think that they used the safeguard.
I12.	Operators behave as though they are experienced.
I13.	Operators cannot explain why they do not use a safeguard.
I14.	Safeguards disturb the work process and production.
I15.	A safeguard reduces the visibility of the tools and activities such as working process, production, setting and so on.
I16.	Poor reliability of safeguards and their failures (e.g. false alarms, trips, and restarts) disturb the people and operations in the work area and stimulate a tendency to bypass.
I17.	Safeguards can be disabled easily and with little effort.
I18.	The required tools or keys for defeating are accessible in enterprises.
I19.	Safeguard removal is necessary to perform activities such as adjustments, troubleshooting, maintenance, and installation (no specific operation modes exist for performing them).
I20.	Coping with faults would be more efficient with safeguard circumvention.
I21.	Removing and installing safeguards frequently for lubrication is tedious.
I22.	Acting quickly to remove products that fall off without interrupting production.
I23.	Producing unusual pieces of work requires a safeguard defeat.
I24.	Bypassing provides convenience and facilitates work.
I25.	Safeguards in place slow down the work process and production.
I26.	Safeguards are difficult to use because they are impractical.
I27.	Other individuals are involved, not just operators.
I28.	An unsuitable safeguard has been selected at the design phase, which is unacceptable for the operator.
I29.	Easy access to software and switches make safeguards possible to defeat.
I30.	Safeguards are not maintained correctly to ensure complete protection.
I31.	A safeguard limits the adequate lighting in a workplace.
I32.	Bypassing increases downtime due to production disturbances.
I33.	A safeguard is an obstruction to quickening the pace of work and enhancing productivity.
I34.	Machinery and safeguards are not user friendly and have poor ergonomics.
I35.	There is not enough workspace when using a safeguard.
I36.	There is a lack of management commitment and managers either ordered, tolerated, encouraged or

Code of incentives	Definition
	ignored circumvention.
I37.	There are no enforcement or disciplinary actions for those who bypass safeguards.
I38.	A safeguard is bypassed to obtain greater precision.
I39.	Safeguard is bypassed to have better audibility.
I40.	Safeguard is bypassed to require less physical effort.
I41.	Safeguard is bypassed to reduce the rate of travel.
I42.	Safeguard is bypassed to facilitate the freedom of movement.
I43.	Safeguard is bypassed to improve the flow of movement.
I44.	Safeguards are bypassed to save time carrying out the operations.
I45.	There is an unsuitable machine to work with.
I46.	Bypassing is a habit.
I47.	Safeguard is bypassed because of stress.
I48.	A safeguard vibrates or rattles.
I49.	Bypassing occurs with experienced operators because they think that they are less at risk than others.
I50.	There is time pressure to perform the job or to meet expectations.
I51.	There is a lack of adequate training and awareness about manipulation.
I52.	Bypassing a safeguard is not detectable; they are usually restored or bosses cannot detect it.
I53.	Employee involvement is ignored when procuring machines or other OHS issues.
I54.	Experienced operators force others to bypass, or defeating is carried out with peers.
I55.	The machine design is poor.
I56.	There is a lack of flexibility in programming (e.g. a program that goes back to the beginning when the machine was stopped for swarf removal, etc., and it cannot be restarted mid-cycle or when the safeguard has to be enabled all the time or just during CNC mode.)
I57.	The regulatory requirements do not clarify whether safeguards should be operated all the time or just when operating in CNC mode.
I58.	There is impaired accessibility to the job and the tools.
I59.	Bypassing occurs to achieve encouragement and performance bonuses from bosses.
I60.	There is no supervision that monitors if a safeguard is enabled.
I61.	Bypassing occurs because of financial pressures.
I62.	Safeguards are not checked before operating the machine to ensure that they are in place.
I63.	The issue of defeating is not integrated into a culture of safety.
I64.	Current policies and procedures are inadequate.
I65.	The time costs due to a program restart are reduced.
I66.	Machines are produced by manufacturers with poor quality safeguards.
I67.	Profitability diminishes if the customer’s order is not met.
I68.	Moving the heavy safeguard is difficult.
I69.	The safeguard’s size makes it difficult to access areas around it.
I70.	Clothing is caught or cuts happen because of the physical characteristics of a safeguard.
I71.	Metabolic energy consumption will decrease by bypassing.
I72.	Taking a risk is exciting for employees.