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PROTECTING WORKERS: PREVENTING WORK-RELATED UPPER-EXTREMITY AMPUTATIONS

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NORWEGIAN SUMMARY – NORSK SAMMENDRAG

Arbeidervern: Forebygging av arbeidsrelaterte amputasjoner

Den teknologiske utviklingen har generelt sett forbedret sikkerhetsstandarden i arbeidsmiljø, men globalt mister arbeidere fortsatt liv og lemmer på arbeidsplasser. ILO anslår at 270 millioner arbeidstakere dør eller blir alvorlig skadet på jobb på verdensbasis hvert år. Amputasjonsskader er sjeldne, men av de mest alvorlige traumatiske skader som oppstår på arbeidsplassen. Farlige maskiner er en kjent etiologisk faktor som fører til slike traumatiske skader. Dermed er det viktig å identifisere hvilke typer forebyggende tiltak som kan redusere risiko for traumatiske skader som skyldes maskiner. Før forebyggende tiltak planlegges eller iverksettes er det viktig å ha kjennskap til omfanget av problemet. Underrapportering av arbeidsrelaterte traumatiske skader som amputasjoner, er en global utfordring, og det understreker behovet for robuste overvåkningssystemer.

Denne avhandlingen er en sammensetning av fire studier som hovedsakelig omhandler forebygging av arbeidsrelaterte amputasjoner. De første to av disse studiene ble gjennomført i Minnesota, USA, og handler om risiko for å bli traumatisk skadet av farlige maskiner og hvilke typer intervensjoner som kan forebygge slike skader. De neste to studiene, som ble gjennomført i Norge, er epidemiologiske undersøkelser av arbeidsrelaterte amputasjoner av øvre lemmer. Den første beskriver skadenes antall og kjennetegn basert på Arbeidstilsynets registreringer for året 2007. Den andre estimerer omfanget av den sannsynlige underrapporteringen av slike skader i tiårs-perioden 1998-2007 ved bruk av en såkalt to-kilde capture-recapture metode. Med utgangspunkt i disse analysene drøftes svakheter i overvåkning av traumatiske arbeidsskader som amputasjoner i Norge.

Basert på disse fire studiene ble det konkludert med at eksponering for farlige maskiner fortsatt er en fare i arbeidsmiljø. Videre viser dataene at tilstedeværelse av arbeidsmiljøutvalg kan gi en beskyttende effekt for arbeidere mot traumatiske skader som amputasjoner. Studiene viser også at små virksomheter, unge menn og arbeidere ansatt i industrinæringen er mest risikoutsatt mht. amputasjonsskader. Til slutt viste studien at norsk overvåkningsinfrastruktur for traumatiske arbeidsskader som amputasjoner er svak, og det anvises mulige tiltak for å gjøre den bedre.

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“Medicine is a social science and politics is nothing else but medicine on a large scale. Medicine as a social science, as the science of human beings, has the obligation to point out problems and to attempt their theoretical solution; the politician, the practical anthropologist, must find the means for their actual solution”.

Rudolf Virchow (1821-1902)

PREFACE

My pursuit of medicine, public health, and eventually occupational health is unconceivable without the constant support of my parents. They provided me with opportunities far beyond their means, and consoled me despite my many failures. My insignificant contributions and achievements if any remain indebted to their unconditional compassion and care.

The tryst with social medicine and public health started when I was a medicine student in Bombay, India in 1992. But, it was not until 1999, that I made a conscious choice to opt for a residency in preventive and social medicine at Grant Medical College, Bombay.

The choice of working in preventive and social medicine is perhaps an expression of my experiences during my medical internship. I witnessed some of the gravest injuries inflicted on the human-body, sometimes fatal, while working at the emergency rooms. The case-histories often indicated that many of the injuries were preventable. These early impressions, at least sub-consciously, shaped my choices and steered me toward population-based approaches to prevention. The time I spent at the preventive and social medicine residency program (1999-2000) provided me with the opportunity to learn and explore more about public health approaches. Moreover, the experiences at the paediatric wards, tending to among others HIV infected neonates born to HIV infected mothers enslaved in flesh trade, left a lasting and deep imprint on my mind. The futility of clinical regimens to treat the maladies of social oppression and injustice became both uncomfortable and blatantly obvious to me.

These disconcerting encounters possibly revealed that health status of an individual could only be as good as the society she or he lives in. By treating the individual patients, we are doing a noble service to mankind, but potentially only alleviating a symptom of the underlying malaise that plagues our societies. It was also at this residency program I was first familiarized to the discipline of occupational health, injury prevention and the plight of the working populations.

Somewhat disillusioned, by my clinical experiences, and catalysed by my growing interest in social medicine and public health led me to pursue a Master in Public Health in the US (fall, 2000). It was in fact Ranjit Mankeshwar Associate Professor, with the Department of Preventive and Social medicine at Grant Medical College who inspired, prodded and encouraged me to follow my passion, and not convention. Moving to the US thus was a life altering decision and eventually led to a career-path within public health, global health and eventually occupational health.

My public health tenure at the University of Minnesota (U of M) under the thoughtful tutelage of Lester Block, Associate Professor with the School of Public Health at the U of M, reinforced my belief in mitigation of morbidities and mortalities using the public health approach. While pursuing my Master in Public Health, I was drawn toward social sciences and attended coursework at the school of social work (2002-2004). Here, I came across the writings of Alice Hamilton (1869-1970) and Rudolf Virchow (1821-1902). It was heartening to know that my leanings toward social medicine and public health were not completely unfounded, rather there was a considerable populace of medical professionals world-wide who espoused the virtues of Virchow, the ideals of Hamilton and even the self-righteousness of Henrik Ibsen's, proverbial Dr. Stockmann.

I have fond memories of my times at the U of M and it certainly shaped my outlook on life. Particularly, the meetings with inspiring medical professionals, both Americans and from around the world, who were passionate about social medicine and public health and were engaged in some extraordinary work. It was in this milieu I crossed paths with one David Parker (spring, 2001) an occupational physician, epidemiologist and an advocate for elimination of child labour at a global health seminar. I credit David for enabling the dormant epidemiologist, and the curious occupational health researcher in me. I have been fortunate to have worked in social medicine, public health, occupational health including my rendezvous with global health for almost 15 years now. Serendipity, indeterminism or destiny, whatever one may choose to call it, is undoubtedly a factor that facilitated my passage from the US to Norway in 2006. The Norwegian people in general, but particularly the bureaucracy and academia have been kind, inclusive and encouraging which has helped me foster my interests and contributed to my personal and professional growth.

This thesis is a culmination of a long journey that I embarked upon many years ago at the University of Minnesota and concludes at the Norwegian University of Science and Technology (NTNU). Looking back, this journey had its moments of tears, joys, despairs and elations. The person who has shared these moments with me is my wife Eva Irene, and our children Ester Indira and Mira Alice. This work is dedicated to these precious people.

Trondheim, 2012, Yogindra Samant

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This academic work would not have been possible without the funding of National Institute of Occupational Safety and Health, USA (NIOSH, grant number R01OH003884) and the financial support of the Norwegian Labour Inspection Authority (NLIA).

I would like to thank David Parker for providing me the opportunity to work on the Minnesota Machine Guarding Study. David has contributed to this work with timely advice and numerous suggestions for improvements in the manuscripts and this thesis. I would also like to acknowledge the work of my co-authors on the papers based on data from Minnesota. I am especially appreciative of the conscientious efforts put in by Kaizad Munshi, Lisa Brosseau, Wei Pan, Min Xi, David Haugan and Todd Bridigum. I would also like to acknowledge the Park Nicollet Institute for providing me with the support and infrastructure for conducting the study in Minnesota.

Visiting more than 50 metal working shops as part of the study in Minnesota was a privilege. I discovered things in the working environment that would have otherwise been inaccessible to me in the academia or as a clinician. I would like to express my gratitude to all the workers and owners who permitted me to gain a unique insight in to the everyday grind on the shop floors. In particular, I would like to recognize the contributions of Eric Ajax from E.J. Ajax, Robert Fischer from Boker's, Inc, and Shale Juster from Juster Industrial, James Krueger Minnesota OSHA and other members of the Minnesota Machine Guarding Study Advisory Board

I would like to thank Steinar Westin, my advisor at the Department of Public Health and General Practice, NTNU for his eternal enthusiasm, positivity and unparalleled ability to inspire me to keep on going. Steinar's quick and precise feedbacks were both intellectually stimulating and provided me with clarity while developing this thesis. The meetings we had over cups of coffee in the corridors at the department, typically on Thursday afternoons, debating the contents of the papers and thesis is something I will cherish for years to come.

My thanks to well-wishers with the Department of Occupational Medicine at the St.Olav Hospital, Trondheim. In particular, Bjørn Hilt for his long-standing support and encouragement of this endeavour, and Håkon Lasse Leira for his warmth, affection and guidance.

Johan Lund from the Institute of General Practice and Community Medicine, University of Olso, has been kind enough to provide me with valuable inputs to this thesis. Especially, our deliberations on accident and injury have been rewarding. My gratitude, therefore to Johan's significant contributions and advise.

A deep sense of gratitude and appreciation for Ebba Wergeland. The compilation of the scientific papers in to a thesis is a product of discourses with Ebba that started sometime in fall of 2007. This thesis is unconceivable without her belief and conviction in both me and the subject of preventing amputations at work. Ebba served both as compassionate colleague and cogent critique, while I have been working on this thesis. She has been the oracle of sorts that I called upon in face of personal and professional barriers. Ebbas contribution to this thesis is literally immeasurable.

This thesis would not be possible without the material and moral support offered by the NLIA. In particular, former director at the Division of Documentation and Analysis (DOA), Stig Maganr Løvas's faith in the utility of this work for NLIAs preventive efforts and his confidence in this project was a decisive factor. I would also like to thank Stig for his pertinent comments while working on the thesis. I am equally grateful to Monica Seem; the current director of DOA who persevered with the confidence instilled in this work, and whole-heartedly supported my efforts toward completion of this thesis. My former and present colleagues at DOA must be thanked for being accommodative and supportive while I have worked on this thesis.

Labour inspectors at the NLIA have shared their first-hand knowledge with me and it was a privilege to be visiting the workplaces with them. I would specifically like to express my gratitude towards Willy Husby, Gunnar Løvås and Anne Marit Kjelbergnes, inspectors with the NLIA (Central-Norway). Also, earnest thanks to Axel Wannag and my physician colleagues at the NLIA for supporting the realization of this work.

I would like to express my appreciation for the efforts of the library personnel at National Institute of Occupational Health (STAMI), Oslo for their very efficient services. I am indebted to Steinar Holm and Kari Mørk with the Association of Norwegian Private Insurance Companies for sharing the injury data that were utilized in this study. I would also like to acknowledge the valuable information provided by Brian Zaidman (Minnesota OSHA) and Dawn Castillo (NIOSH) on the surveillance of work-related amputations in the US.

LIST OF PAPERS

This thesis is based on the following four publications:

Paper I	Samant Y, Parker D, Brosseau L, Pan W, Xi M, Haugan D. Profile of machine safety in small metal fabrication businesses. Am J Ind Med 2006; 49: 352-9.
Paper II	Parker DL, Brosseau LM, Samant Y, Xi M, Pan W, Haugan D. A randomized, controlled intervention of machine guarding and related safety programs in small metal-fabrication businesses. Public Health Rep 2009; 124 Suppl 1: 190-100.
Paper III	Samant Y, Parker D, Wergeland E, Westin S. Work-related upper-extremity amputations in Norway. Am J Ind Med 2012; 55: 241-9.
Paper IV	Samant Y, Parker D, Wergeland E, Lund J, Westin S. Estimating work-related amputations in the Norwegian manufacturing sector: A 10-year retrospective study based on two-source capture-recapture method. Int J Occup Environ Health 2012; 18: 292-98

2. ABBREVIATIONS

ANPIC	Association of Norwegian Private Insurance Companies (DAYSY registeret*)
ANSI	American National Standards Institute
BBS	Behaviour Based Safety
CDC	Center for Diseases Prevention and Control
ESAW	European Statistics for Accidents at Work
GDP	Gross Domestic Product
ILO	International Labour Organization
NACE	Statistical Classification of Economic Activities in the European Community (in French: Nomenclature statistique des activités économiques dans la Communauté européenne)
NIOSH	National Institute of Occupational Safety and Health
NLIA	Norwegian Labour Inspection Authority (Arbeidstilsynet*)
NLWA	Norwegian Labour and Welfare Administration (NAV*)
OECD	Organization for Economic Co-operation and Development
US BLS	United States Bureau of Labor Statistics
US OSHA	United States Occupational Safety and Health Administration
RWI	Norwegian Registry of Work-Related Injuries (Yrkesskaderegister*)
SIC	Standard Industrial Classification

*Norwegian designations

3. ABSTRACT

Background

Technological developments have improved safety standards in workplaces, but workers around the world still continue to lose their lives and limbs. Amputations at work are rare, yet preventable traumatic injuries that have psychological, physical, and economic implications for the injured worker. Hazardous machines are a known etiological factor that leads to amputations at work.

The magnitude and nature of a problem needs to be understood before designing and implementing preventive interventions. The underreporting of traumatic injuries at work, such as amputations, remains a global challenge, underscoring the need for robust surveillance systems. Better surveillance systems will in turn yield sound epidemiological data to design and implement preventive interventions.

The four papers included in this thesis share a common goal of informing the development of effective preventive interventions and enhancing surveillance mechanisms to reduce the risk of work-related upper-extremity amputations.

This thesis first reviews the principal theories and contemporary definitional discourse in the field of workplace injury prevention. Thereafter, four studies that constitute this thesis are presented. The first two papers concern the assessment of hazardous machines that cause traumatic injuries, such as amputations, and evaluation of injury prevention intervention based on studies in Minnesota. The next two papers address the issues of the epidemiology and surveillance of work-related upper-extremity amputations based on studies in Norway.

Specifically, Paper I presents the baseline findings of a randomized controlled intervention study on machine safety conducted in Minnesota. Paper II summarizes the results of a randomized controlled intervention study on improving machine safety and related safety programs. Paper III reports the results of a study on the epidemiology of work-related upper-extremity amputations in Norway. Paper IV concerns the surveillance of work-related upper-extremity amputations in the Norwegian manufacturing sector.

Study in Minnesota (Papers I and II)

Materials and Methods

The study in Minnesota, United States (2002-2008), is based on data on the risk of traumatic injuries in general and amputations in particular attributable to hazardous machines. The data were collected from metal-working businesses using validated checklists before and after the application of an injury prevention intervention. The outcome of interest in this study was the level of safety of metal fabrication machines with regard to their compliance to best machine-guarding practices. The data are essentially measures of worker exposure to hazardous machines. In addition to the levels of safety of the machines, data on organizational variables, such as the presence or absence of safety committees, unionization, the presence of health and safety programs, and training, were also collected. Based on these data, each business received a machine score and shop safety score.

The 40 businesses that participated in this study were randomly assigned to two groups after the baseline measures were taken. Each group comprised 20 businesses. One group (n = 20) included worker and management representatives, and the other group included only management representatives (n = 20). The worker-management group received the full intervention that included a report based on the baseline evaluations of machine safety and health and safety programs in their businesses, including a compact disk (CD) with resource and training material. Additionally, this group was offered four training sessions. The management-only group received a minimal intervention that included the report based on the baseline evaluations and a CD with resource and training material. Of these 40 businesses, three were lost to follow-up. Thus, a total of 37 businesses were followed-up. The worker-management group and management-only group comprised 19 and 18 businesses, respectively.

Results

During the baseline measurement, a total of 824 machines were evaluated in 40 businesses. Overall, 55% of the items that addressed guarding on the machines were present. No single machine complied with all of the critical safety requirements across the 40 businesses. The businesses with safety committees had better scores than those without safety committees. The baseline mean-machine scores were 63% in the worker-management group and 64% in the management-only group. The mean shop safety scores were 66% and 64% for the worker-management and management-only groups, respectively. The mean machine scores significantly improved over baseline at follow-up by a similar amount (4-5 points) in each of the intervention groups. Similar changes were also observed in shop safety scores in both groups, but were not statistically significant. We did not observe differences in the magnitude of change in either the shop safety or machine safety scores between the two groups.

Study in Norway (Papers III and IV)

Materials and methods

The two studies conducted in Norway utilized surveillance data on upper-extremity amputations registered in the Norwegian Labour Inspection Authority (NLIA) Registry of Work-Related Injuries (RWI) and Association of Norwegian Private Insurance Companies Registry of Occupational Injuries (ANPIC). The first study was descriptive and characterized the epidemiological profile of upper-extremity amputations in Norway in 2007. The second was a retrospective study that estimated the annual number of amputations over a 10-year period (1998-2007) in the manufacturing sector, utilizing a two-source capture-recapture method.

Results

The descriptive study that utilized surveillance data in Norway was based on injuries reported to the RWI in 2007. One hundred forty-nine upper-extremity amputations were reported in 2007. The estimated annual incidence of upper-extremity amputations was 6/100,000 workers. Males aged 20-24 years had the highest incidence rates. A majority of the amputations (n = 111) were clustered in businesses with 49 or fewer employees. The incidence was highest in businesses with 1-9 employees. Manufacturing accounted for 36% of the amputations. Fingers were the most frequently amputated body part.

The capture-recapture study estimated the number of amputations within the manufacturing sector for the 10-year study period (1998-2007). The two sources utilized in this study were the NLIA and ANPIC injury registries. We estimated an annual incidence that ranged from 21 to 62 per 100,000 workers during the study period. Our findings suggest that the undercounting of amputations reported to the NLIA registry varied from a minimum of 16% to a maximum of 58% during the study period.

Conclusions

Machines, particularly in the manufacturing sector, remain a source of hazardous exposure that can lead to traumatic injuries, such as amputations. The presence of safety committees may help reduce the risk of amputations caused by machines. Amputations at work are rare events and remain underreported in national surveillance systems in Norway. Establishing robust surveillance systems that may provide reliable epidemiological data for designing effective preventive interventions is critical.

5. INTRODUCTION

The International Labour Organization (ILO) constitution sets forth the principle that workers should be protected from sickness, disease, and injury that arise from their employment (1). For millions of workers globally, the reality remains different. The pain and grief caused by traumatic injuries at work that workers and their families suffer are immeasurable. In economic terms, the ILO has estimated that 4% of the world's annual Gross Domestic Product (GDP) is lost as a consequence of work-related diseases and injuries (1). Employers also face the challenge of early retirement, the loss of skilled staff, absenteeism, and high insurance premiums because of work-related injuries. The tragedies that ensue from the loss of workers' lives and limbs are avoidable by implementing engineering interventions, providing safety and health education, instituting safety committees and safety representatives, providing and using personal protective equipment, and ensuring robust regulatory enforcement.

The public health approach identifies and targets workers in high-risk occupations that are underserved by traditional occupational health and safety programs and areas where wide gaps in injury rates and hazards exist between those who perform similar tasks. Surveillance, risk factor identification, intervention development, implementation, and evaluation are central tenets of a public health approach to workplace injury prevention (2).

Work-related amputations are rare but serious injuries that have grave economic, physical, and psychological implications for workers, their families, and society at large. Despite improvements in machine safety, work-related amputations remain an enduring global challenge (3-6). Improving machine safety through machine-guarding practices will help prevent amputations and other traumatic injuries in the workplace. For example, a safety guard on a power press that creates a barrier to protect a worker's hand from entering the point of operation will also prevent objects from flying from the point of operation and hitting the worker's eyes or other vital organs.

This thesis first reviews the principal theories and contemporary discourse on the application of the terms "accident" and "injury" in the discipline of workplace injury prevention. Four studies on the prevention and surveillance of work-related amputations are then presented. The findings of this thesis attempt to inform strategies and policies for the prevention of work-related traumatic injuries in general and amputations in particular.

5.1 Study settings

Although this study spanned two countries with different political and social structures, it addresses the common theme of preventing work-related amputations. Similarities were also found between the two study settings, namely the state of Minnesota in the United States and Norway.

In the context of these four studies, the nature of exposure that leads to an amputation is a critical commonality. Specifically, the lack of machine guards is a known etiological factor for amputations globally. The manufacturing workforce in both Minnesota and Norway consists of approximately 250,000 employees (7,8). In fact, the largest number of work-related amputations were attributed to manufacturing in both Minnesota and Norway (9, 10). The author of this thesis is another common factor in these studies. He has accrued know-how on the prevention and surveillance of traumatic work-related injuries, including amputations, because of his engagement in research, policy, and practice with regard to injury prevention in both Minnesota and Norway (2002-2012).

Minnesota and Norway, among others, share a Scandinavian heritage and have a similar population in terms of numbers (approximately 5 million each). Minnesota, as part of the United States, and Norway are both OECD members, and both Minnesota and Norway have been influenced by centre-left politics in recent years. This somewhat comparable background provides an opportunity to explore the challenge of preventing work-related amputations in a trans-Atlantic context.

5.2 Accident and injury prevention in the workplace

5.2.1 Accidents or injuries

To address a specific problem within a scientific framework, it first needs to be clearly delineated. In the field of workplace injury prevention, accidents and injuries are terms that are often used synonymously. This is problematic. One issue of contention is the ambiguity of the term *accident* because of its numerous meanings and connotations, and another, more pressing issue is the common fallacy of equating an accident with an injury.

The term *accident* has a connotation that associates it with the supernatural, irrational explanations, fate, destiny, misfortune, chance, and luck (11-13). Andersson’s study of Swedish workers indicated a strong tendency of victims to attribute the principal cause of an accident in the workplace to supernatural, irrational explanations or blaming themselves (14). According to Loimer, because of its Biblical connotation (i.e., an act of God), “The word accident often obstructs the study of injury prevention” (11).

The term *accident* is derived from late Middle English to mean an event in a general sense, but it also comes from the Latin word *accidere*, to fall (15,16). An “accident”, simply put, is an event, series of events, or social phenomenon that is unintentional in its nature and precedes an injury (17). The term *injury* is derived from the Latin *injuria*, a wrong (16). An injury is an observable physical manifestation of an event at work (17). If the event that results in an injury is intentional in its nature, then it is no longer an accident (e.g., injuries caused by acts of violence in the workplace). Moreover, although an accident may result in an injury, it can also lead to environmental or material damage without causing any injuries or casualties to personnel.

The necessity of discerning these two terms can be exemplified by examining a work-related amputation. A work-related amputation is not necessarily an inexplicable event resigned to fate. Rather, the amputation plausibly resulted from the hazardous nature of the machine, work pressures, or lack of training, leading to the transfer of mechanical energy from the machine to a body part. The chain of events that preceded the amputation can be reconstructed by the injured worker, co-workers, the foreman, managers, and other witnesses. The various narrative reconstructions of the events that led to the amputation provided by the victim and witnesses may or may not be congruent.

Training in machine safety will certainly contribute to the creation of barriers by raising worker awareness of the hazards associated with operating the machine and thus may prevent the events that lead to an amputation. However, the most effective way to prevent amputations (injuries) is to adequately safeguard the hazardous parts of the machine. The comprehension of this nuanced distinction between accident and injury is vital when designing injury prevention interventions and regulatory policies. The reason for differentiating an accident from an injury, therefore, seems obvious. Health-related disciplines have generally subscribed to this distinction and discourage the use of the word *accident* in the injury prevention lexicon (18-21).

Injury prevention must be acknowledged as an interdisciplinary field that includes professional disciplines beyond public health and medicine. Engineers, social scientists, and psychologists continue to make valuable contributions to the field of accident and injury prevention. Many of these professionals continue to embrace the term *accident* and assert that such a term is not a hindrance to injury prevention (22). Among other things, advocates of the term *accident* suggest that it incorporates a wider spectrum of harm, including, but not limited to, human health (22). The contention is that such an approach accounts for social, political, and organizational perspectives to prevent accidents and injuries (22). Additionally, some assert that we do not have a better term than *accident* to signify multiple injuries that occur from a single human environmental interaction (event). Furthermore, the complexity of the events is not completely captured by the term injury (23).

Norwegian injury epidemiologist Johan Lund, in an attempt to resolve this argument, proposed the term "accidental injury." He claimed that, unlike the English language, the term *accident* in Nordic languages (e.g., Norwegian/Danish = *ulykke*; Swedish = *olycka*) does not have connotations that ascribe it to the supernatural or destiny (24). However, Norwegian, Danish, and Swedish language dictionaries offer *chance*, *misfortune*, and *destiny*, together with *serious injuries* and *catastrophes*, as several meanings of the word *accident* (12, 25-26).

In a telephone survey of the general public in the United States (n = 943), Girasek found that 83% of the respondents associated the term *accident* with preventability (27). However, 71% of her sample reported that accidents could not be predicted (27). Girasek concluded that although she does not advocate for increased use of the term *accident* in the field of injury prevention, calls for the elimination of the term *accident* are not empirically founded (27). Nevertheless, she acknowledged that missing the distinction between an injury and accident may result in missed opportunities to prevent injuries (27). This is a critical, yet often unnoticed, inference in the discourse on the terms *accident* and *injury*. The intuitive benefits of using the term *accident* are negated if it is used as a synonym for *injury*. However, general agreement appears to exist among the proponents of the term *accident* that an accident is an event, whereas an injury is a consequence (17,24,28-29). Nevertheless, those who support the term *accident* have failed to forcefully communicate this distinction to the general public, media, and bureaucracy. Subsequently, using the term *accident* as a synonym for *injury* prevails in both the media and regulatory authorities, including the academia. This naive application of the term, in fact, has research, policy, and practice implications in the field of workplace injury prevention (30). For example, the tenuous nature of epidemiological injury data can be partially ascribed to the overt focus of regulatory authorities (e.g., NLIA in Norway) on "accidents", in which traditional accident investigations focus on the technical aspects of the event, and the conscientious collection of injury data appears to be subordinate, consequently compromising the availability of epidemiological data (30).

Davis, Langley, and Doege advocated purging the term *accident* from the injury prevention lexicon because of its several meanings and connotations that hinder prevention (18, 31, 32). Samant and Wergeland revisited this issue in 2011 and suggested a more modest and inclusive view (33). Samant and Wergeland appreciate the value of using the term *accident* in injury prevention, but make a strong plea for stringent application of this term only to describe the event or events that precede the injury (33). Accordingly, for the purpose of this study, a distinction is made between the terms *injury* and *accident*.

5.2.2 Two approaches to injury prevention in the workplace

There are two fundamental approaches to the prevention of workplace injuries. The first pursues the individual worker, and the second focuses on the work environment as a potential explanation for injuries. These two approaches shaped a range of theories that can be found in the discipline of workplace injury prevention.

Individual approach

This approach attributes the burden of injury to an individual's predisposition and heredity. It also encompasses interventions that attempt to modify the unsafe behaviours of individual workers. Specifically, the notion of "accident proneness" (*ulykkesfugl* in Norwegian) is based on the concepts of individual predisposition and heredity. The era of accident proneness dominated the early part of the 20th century until about the 1960s. The significant influence of accident proneness in the early part of the 20th century is ascribed to at least two factors. First, the notion of the "accident prone worker" in the United States should be viewed within the framework of its self-professed role as a frontier society, with a major emphasis on individual responsibility for coping with the environment (34). In other words, the United States was a society that held the belief that the social problems of an individual are a function of his or her psychological or biological inferiority, colloquially known as "victim blaming" (*jakt på syndebukker* in Norwegian). Second, the emergence of applied psychology as a profession in the early part of the 20th century was an important factor in the development and application of the concept of accident proneness (35).

It is claimed that the notion of accident proneness essentially draws on the Freudian view
that we sometimes have unconscious desires to punish ourselves as a kind of penance for wrongdoing or guilt that can be manifested quite frequently in some guilt-laden individuals as accident proneness (36).

In 1925, the psychologist Eric Farmer introduced the term "accident proneness" in his paper on differential tests[1] for susceptible workers. Farmer and his colleagues developed tests that assess the capacity of worker coordination and concentration. They claimed that accident-prone workers act faster than they think, and tests can detect this impulsive behaviour that is a critical cause of accidents (37). Farmer and Chambers defined *accident proneness* as a personal idiosyncrasy that predisposes an individual to a higher injury rate (38). Around the same time but independently, the concept of accident proneness (*unfallneigung* in German) was also claimed by Karl Marbe (1869-1953), another psychologist (37).

Herbert William Heinrich (1886-1962), a pioneering American safety engineer, also referred to the phenomenon of "accident proneness" in his work on accident prevention in 1931 (39). Heinrich popularized the notion that 98% of all accidents are preventable, of which 10% can be prevented through improved techniques, and 88% are the result of the unsafe acts of workers. The remaining 2% of accidents were "acts of God". Heinrich also proposed the domino model of accident causation. He perceived the following five dominoes: (*i*) ancestry and social environment, (*ii*) personal fault, (*iii*) unsafe act or condition, (*iv*) accident, and (*v*) injury. Moreover, Heinrich maintained that removal of any one domino breaks the propagation of the accident (39). Although Heinrich believed firmly that human failure in individuals was the major cause of accidents, he deserves credit for promoting the principles of machine-guarding at the point of operation to reduce machine-related injuries (39).

The accident proneness theory was widely criticized just before and after World War II (37). There were several reasons for this criticism. First, studies claimed that accident proneness had low correlations with psychological test results and accident figures. Second, doubts were cast on the validity of these studies because of tenuous data quality, the influence of temporal factors, and ambiguousness in defining the concept "accident proneness" (40-42). Finally, the notion of accident proneness applies the concept of homogeneity, both for the groups of people studied and the risks of exposure. This assumption of homogeneity was considered dubious because workers with the same tasks are unlikely to be exposed to identical risk factors. This was a vital argument because only a solitary factor (i.e., accident proneness) was taken into account to explain accident causality (37). None of the research studies on accident-prone workers provided any information about the types of accidents. The focus was only on the injuries, bodily harm, and psychological stability of the victim (37,43,44). Despite the criticism, accident proneness engenders some degree of instinctive appeal, remaining a subject of academic discourse and thriving in popular culture (35,45-47).

The censure of the individual approach is to the extent that it explains workplace injuries solely on the basis of heredity and individual traits and does not consider physical or organizational factors in the work environment. Behaviour Based Safety (BBS) programs focus on individuals, but such programs typically claim to include environmental components (48,49,50). Moreover, advocates of BBS programs recognize the importance of environmental factors in the workplace that influence behaviour (48,50). However, despite their widespread-application, BBS programs remain contentious because they consider "the individual" as the unit of analysis and therefore are often accused of blaming victims (i.e., workers) for their injuries (51,52). Several studies have suggested a combined approach that includes engineering, administrative, and behavioural interventions to mitigate the risk of workplace injuries (53-55). For example, social cognitive theory offers opportunities to combine behavioural and environmental components in an injury prevention intervention (48). Social cognitive theory posits that an individual's (i.e., workers) actions are not necessarily controlled only by their environment and are not necessarily self-determining; instead, individuals exist in a state of "reciprocal determinism"[2] in their environment, in which workers and their environments influence each another in a perpetual dynamic interplay (48).

The study conducted in Minnesota included components of social cognitive theory that is described elsewhere (56), but is not integral to this thesis, in which the unit of analysis was the business.

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[1] Psychometric tests

[2] **Reciprocal determinism** is the theory set forth by psychologist Albert Bandura (b. 1925) that a person's behaviour both influences and is influenced by personal factors and the social environment. Bandura accepted the possibility that an individual's behaviour is conditioned through the use of consequences. At the same time, he asserted that a person's behaviour (and personal factors, such as cognitive skills or attitudes) can impact the environment.

Environmental approach

This approach attributes the burden of injuries to factors in the work environment, such as the speed of work, dangerous machines, and long work hours (37). The environmental approach is compatible with both energy transfer- and systems-thinking-based theories in the field of accident and injury prevention (42,57).

Crystal Eastman (1881-1928), a sociologist in the United States, differed from the general opinion during the early part of the 20th century (1910), which embraced the notion of accident proneness (37). Eastman maintained that accident causation, including crush injuries and fatalities, should be understood from the conditions of labour, long work hours, high-speed production, high temperatures and noise levels, young age, low levels of worker experience, and the continuous presence of various hazards associated with machines because of deficient machine guards (58). Specifically, she claimed that injuries at work are a function of the work environment and not individual predisposition (58).

Eastman's assertions, although quite revolutionary for the rapidly growing industrial landscape of the United States, were strikingly similar to the critique made by Friedrich Engels (1820-1895) in 1844 on the working environments in the factories of England. Among other appalling narratives on the conditions of toiling labourers in textile mills, Engels recounted that the most common injuries in textile spinning mills was the squeezing off of a single joint of a finger; somewhat less common was the loss of a whole finger, half or whole hand, or arm in the machinery (59).

In 1848, Rudolf Virchow (1821-1902), the father of social medicine, was one of the first physicians who made a scathing critique of the work environment of miners in Upper Silesia and impact of machines on the human condition. He is famously quoted:

"All the world knows that the proletariat of our day has been mainly brought into existence by the introduction and improvement of machinery; that in proportion as (industry) through the perfectionment of apparatus, acquired an unprecedented extension, man-power has completely lost its autonomy, and human beings have become incorporated as mere cog-wheels in machine enterprise, living cog-wheels, indeed, but treated as of no more value than dead matter. The human instruments are regarded as mere 'hands'! Are the triumphs of human genius to lead only to this, that the human race shall become more miserable? Unquestionably not. . . . Man should only work as much as is needful . . . but he should not waste his best energies in producing capital. Capital is a title to enjoyment; but why should this title be increased to a degree beyond all reason?" (60).

Kinder Wood (1785-1830), a surgeon in England, testified before the Commission on the Employment of Children in 1816 and advocated for an intervention in the work environment to protect child workers from traumatic injuries that result from machines. Specifically, he suggested that the ceilings of mills should be higher so that children caught in the machinery might revolve without being crushed (61).

A monetary dimension of the issue also needs to be considered with regard to the choice of individual as opposed to environmental approaches to injury prevention. The employer typically bears the costs of safety improvements, but both regulatory authorities and employers are likely to evade stringent regulatory demands to reduce the regulatory burden (41), creating an "investment friendly atmosphere." Proponents of the individual approach who intend to modify worker behaviour conceivably offer a less expensive option that is directed toward individual workers, such as personal protective equipment, compared with advocates of the environmental approach who may recommend relatively expensive engineering interventions to improve the overall work environment (62).

5.2.3 Theories of workplace accident and injury prevention

The two central approaches described in the preceding section provide the foundations for various theories of accident and injury prevention. Briefly, these have been classified chronologically into the following four generations (64):

I. Accident proneness theory (circa 1919)
II. Domino theory (circa 1931)
III. Epidemiological theory (circa 1964)
IV. Systems theory (circa 1970)

I. Accident proneness theory

Accident proneness theory ascribes accidents and injuries to individual traits and heredity. This notion was discussed in the previous section and is no longer the dominant thought in the field of accident and injury prevention in the workplace. However, studies that embrace this theory continue to appear in the contemporary literature (47, 64).

II. Domino theory

Heinrichs' Domino theory focuses on five dominos, namely social environment and ancestry, fault of the person, unsafe act, accident, and injury, which may lead to an error of generalization. In practice, an unsafe act is the ''easiest-to-blame'' domino, consequently leaving hazardous factors in the work environment generally unattended (65).

III. Epidemiological theory

Epidemiological theory identifies the following three factors to explain the injury phenomenon: the host (the person injured), the agent (the energy that leads to an injury), and the environment (physical, biological, and organizational). This theory has been criticized because of a lack of focus on the interactions between the host, agent, and environment before the injury occurs, also known as the pre-event phase (28). Moreover, descriptions of the application of this theory in different types of work systems are also allegedly scarce (65).

IV. Systems theory

Systems theory is applied to numerous disciplines to understand interactive dynamics and the conditions for stability and control. It considers mutuality, interaction, and complexity as vital keys to understanding accident causation (22). In a comprehensive review of research on occupational accidents and injury, Khanzode and co-workers acknowledged that the prevailing systems-based theories can only analyse and explain "accident" causation, without addressing aspects of injury prevention (65). In terms of workplace injury prevention, saving lives and limbs ought to supersede material and environmental damage, including production losses. Systems theory-based models appear to equate the losses of money and material with human loss.

Accident models that emanate from systems theory no doubt concern the prevention of the loss of human life, but are more likely targeted toward the prevention of high-technology disasters or catastrophes (e.g., Chernobyl, Bhopal) and not necessarily injury prevention in the workplace (66).

A detailed discussion of the multitude of theories in the field of accident and injury prevention is beyond the scope of this thesis, but this issue has been explained in treatises that focused on accident and injury prevention (28,39,42,67-72). Epidemiological theory is more pertinent to this thesis and will be discussed in some detail in the following section.

5.2.4 Epidemiological theory of injury prevention

The Norwegian academic Jan Hovden, a veteran in the field of occupational safety, states in his paper titled, "A need for new theories, models and approaches to occupational accident prevention?" that most models in the field of accidents are still based on the concepts developed by Heinrich (1931), Gibson (1962),[3] and Haddon (1968) (73). Hovdens' proposition appears to endorse the perennial value of Haddon's epidemiological theory to the field of injury prevention, which again was inspired by Gibson's notion of energy interchange (energy transfer).

William Haddon, Jr. (1927-1985), was a physician, engineer, and public health advocate and is widely considered the father of injury epidemiology (74). Haddon introduced the concept of ecological injury prevention with the publication of his seminal paper, "On the escape of tigers: an ecological note" (75). He explained the notion that an injury occurs through the transfer of energy, of which there are several types: kinetic, thermal, chemical, electrical, and ionizing radiation. Damage to the body results when energy is transferred in quantities or rates that the body cannot withstand. Haddon drew parallels between injury causation and the infectious disease process (i.e., the transfer of infectious agents to the human host) (75). Likewise, the transfer of energy from a machine to a human arm can result in a traumatic injury, such as an amputation. The application of epidemiology in the field of injury prevention is essentially an ecological approach that looks at circumstances and environmental factors rather than focusing on individual predisposition and personality traits as the cause of injury. These ideas eventually culminated in what is known as Haddon's Matrix, a paradigm in the field of injury prevention.

Table 1 below provides an illustration that applies Haddon's Matrix to the prevention of amputations at work.

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[3]Haddon's epidemiological theory, among others, is based on concepts originally developed by Cornell psychologist James Gibson (1904-1979) and Harvard epidemiologist John Gordon (Obituaries missing) (74).

Table 1. Application of Haddon's Matrix to the prevention of machine-related amputations.

	Host	**Agent**	**Physical Environment**	**Social Environment**
Pre-event (before amputation)	Training in machine safety Avoid loose clothing and jewellery	Presence of machine guards and devices Evaluate machine-related hazards	Uncluttered work area, good lighting, slip-free surfaces Visible marking of hazardous machine parts	Improve market surveillance to identify hazardous machines Enforce and improve regulatory legislation to reduce machine-related hazards
Event (during amputation)	Training in machine safety	Presence of emergency stop to halt the machine immediately	Develop a crisis management plan for safe and professional handling of the situation	Assistance from co-workers Quality of emergency assistance
Post-event (after amputation)	Provide training in first-aid Provide workers with training in crisis management	Design machines to facilitate easy release of a crushed part Evaluate the machine again for any hazards	Ensure well-trained emergency medical personnel Expedited access to trauma care facilities	Public support for quality trauma care and rehabilitation

5.3 Definitions

Accident at work is an event, series of events, or social phenomenon that is unintentional in its nature and precedes an injury. However, an accident may not necessarily lead to an injury. For example, an accident at work may result in environmental damage or material damage without any injuries or casualties to personnel.

Association of Norwegian Private Insurance Companies registry of occupational injuries (ANPIC). Employer-financed insurance provides compensation to injured workers above and beyond state-financed worker compensation. All employers in Norway are obligated to provide insurance coverage for their workers. The injured worker must file the compensation claim with the employer's insurance company. Private insurance companies in turn send injury data to ANPIC, which is the basis for their registry of occupational injuries (ANPIC registry).

Work-related amputation is a partial or complete loss of an extremity, including digits, as the result of a work-related injury. For the purpose of this study, the term *amputation* generally applies to the upper-extremities, which are the most frequently lost body parts at work.

Work-related injury is an injury caused in the workplace by acute exposure to physical agents, such as mechanical energy, heat, electricity, chemicals, and ionizing radiation. An injury may also be caused by the absence of energy (hypothermia) or oxygen (asphyxiation). The aforementioned elements interact with the body in amounts or rates that exceed the threshold of human tolerance.

Capture-recapture method involves capturing a sample of cases from the population of interest, marking them, releasing them, and then capturing a second sample to ascertain the intensity with which the first sample captured cases from the population.

Hazard in this context is defined as a source of danger.

Lockout/tagout (LO/TO) or **lock and tag** is a safety procedure that is used in industry to ensure that dangerous machines are properly shut off and not started prior to the completion of maintenance or servicing. It requires that hazardous power sources be "isolated and rendered inoperative" before a repair procedure begins. "Lock and tag" works in conjunction with a lock that usually locks the device or power source with a hasp and placing it in such a position that no hazardous power sources can be turned on. The procedure requires that a tag be affixed to the locked device that indicates that it should not be turned on.

Machine guards are safety mechanisms that are essential for protecting workers from moving machine parts that have the potential to cause workplace injuries, such as crushed fingers or hands, amputations, burns, and blindness.

Norwegian Registry of Work-Related Injuries (RWI). The employer in Norway is obligated to report compensable work-related injuries to the Norwegian Labour and Welfare Administration (NLWA). Copies of these injury reports are sent to the Norwegian Labour Inspection Authority (NLIA) where they are registered in the RWI.

Safety Committee is a joint worker and employer committee established by businesses to address issues that concern occupational health and safety. In Norway, the employer's representatives are appointed by the management, whereas worker representatives are elected by the workers. Moreover, the safety committee requirement applies to businesses that employ 50 or more workers and businesses in which the workers or owners mutually agree on establishing such a committee. Additionally, the NLIA may require certain businesses to establish a safety committee if the NLIA deems it to be necessary. In Minnesota, businesses with more than 25 workers are required to establish a safety committee. Furthermore, businesses that have insurance premiums in the top 25% for all classes or those that have experienced a "days away, restricted, or transferred" rate within the top 10% of all rates for employers in the same industry must also establish a safety committee. The clauses of the establishment and composition of safety committees are regulated by law in Minnesota and Norway, but the Norwegian regulation is more detailed on several counts (e.g., appointment of a chairman of the committee, term of the committee, and clauses of confidentiality). Similar clauses are found in Minnesota as well but only in the form of guidelines and are not legally binding.

Small business in the American context is < 250 workers, whereas in the European context is < 50 workers.

Trade union density corresponds to the ratio of wage and salary earners who are trade union members, divided by the total number of wage and salary earners.

5.4 Extent of the problem

The ILO states that there are an estimated 270 million fatal and non-fatal work-related injuries per year world-wide (1). Amputations are rare, but one of the most grievous traumatic injuries that still occur in workplaces globally (76-80).

The epidemiology and surveillance of work-related amputations in particular have been investigated by many researchers (80-88). A substantial body of intervention studies have focused on the prevention of traumatic injuries in the workplace (54,55,86,89-93). Research on small businesses within the field of occupational health, including intervention studies is gradually increasing (55,89,94,95). However, few if any of these studies collectively address the issue of effective preventive interventions to reduce work-related amputations in small businesses. Furthermore, to our knowledge, no scientific investigations have been conducted in Norway that concern the epidemiology and surveillance of work-related upper-extremity amputations.

5.4.1 Epidemiology of work-related amputations

Work-related amputation data from the United States Bureau of Labor Statistics (US BLS) during the period 1992-1999 indicate that 64% (n = 171) of fatal amputations in the United States were attributable to occupations, such as fabricators and machine operators (96). The US BLS estimated an annual incidence of work-related amputations of 6 per 100,000 (97). The Minnesota Sentinel Event Notification System for Occupational Risks (SENSOR) reported that the annual incidence of amputations within manufacturing in Minnesota was 40 per 100,000 workers. Cutting machinery and presses, commonly found in metal-working industries caused 25% of the amputations in manufacturing (85,98).

The European Union’s report on work-related injuries noted that amputations accounted for the highest average number of days lost from work (n = 102 days) compared with other work-related injuries (99). Sorock and co-workers reported that the annual incidence of traumatic work-related hand injuries, including amputations, in seven manufacturing units around the world ranged from 4 to 11 per 100 workers (100).

The ILO has identified metal cutting saws, presses, lathes, and drilling machines as the most hazardous machines based on relative accident frequency per machine (101). These machines often lead to serious injuries, such as amputations, crush injuries, and sometimes fatalities.

In Nordic countries, a substantial number of studies on the prevention of traumatic work-related injuries have been conducted (90, 102-109). Nevertheless, the number of studies that have focused specifically on traumatic hand injuries at work are limited (102, 105-109). Moreover, epidemiological and surveillance literature on work-related amputations is generally lacking in Nordic countries, despite the fact that recent data from Finland and Sweden found annual incidence rates of work-related amputations of 9 and 15 per 100,000 workers, respectively, which were comparable to the rate in the United States (110).

In Norway, some remarkable work on the reconstruction of extremities following amputations is credited to Astor Reigstad. Reigstad conducted the first allotransplantation of a hand in Norway in 1984, based on procedures developed by Chen and co-workers in China (111). More recently, Kristin Østlie made valuable contributions to research on the rehabilitation of patients with acquired upper-extremity amputations in Norway (112). These studies have primarily dealt with the treatment and rehabilitation aspects of amputations.

In Norway, epidemiological studies on the prevention and surveillance of traumatic work-related injuries have been uncommon compared with studies on work-related diseases. However, some significant studies on traumatic work-related injuries have been published over the past four decades (113-122). Moreover, the scholarship of three Norwegian physicians is noteworthy. A doctoral dissertation written by Nils Bull, Risk factors for occupational injuries (2002), Astor Reigstads book on Epidemiological studies of work-related injuries (1978) and Inggard Lereims report concerning Hospital data on occupational injuries (113,115,121).

Moreover, other valuable scientific investigations have attempted to address issues concerning the under-reporting of fatal work-related injuries, the need for hospital-based surveillance of work-related injuries, work-related injuries in high-risk sectors and traffic-related injuries (113-122). For reasons of brevity, these investigations are not described in detail here. The aforementioned studies have contributed considerably to the evolution of the discipline of workplace injury prevention in Norway, but none of these investigations have investigated the epidemiology, surveillance, or prevention of work-related amputations in particular.

5.4.2 *Small businesses and risk of work-related traumatic injuries*

Small businesses are increasingly acknowledged as an asset for economic growth and employment globally. However, small businesses also present a considerable challenge in terms of their survival in a competitive market that mandates cost-saving measures. Typically, occupational safety and health programs in small businesses are the first victims of cost-saving measures. The inability of small businesses to comply with legal requirements is often attributed to a lack of resources, which in turn leads to higher occupational risks in small businesses compared with large businesses (124). Moreover, small businesses in particular can arguably be considered a form of precarious employment because they tend to employ a disproportionately higher number of temporary, part-time, home-based, and other types of workers than larger businesses (125).

Hasle and Limborg identified several studies in which workers employed in small businesses were found to have a higher risk for fatal and severe injuries than workers employed in larger businesses (89). Similar results have been reported for small businesses in the United States. For example, in a study of 253 small businesses, the National Institute for Occupational Safety and Health found that one-third of all workplace fatalities occurred in business establishments with 20 or fewer employees, and at least half occurred in establishments with fewer than 100 employees. Many of the small-businesses had morbidity and mortality rates that exceeded the average rates for all private industry (126).

A survey of 268 small businesses in Norway ($\bar{X}$ = 9 workers) showed that 72% of the participating businesses lacked risk reduction programs. In 28% of the surveyed businesses, the machines lacked protective equipment (127). A NLIA report suggested that workers employed in smaller businesses were 1.5-times more likely to sustain an amputation injury compared with larger businesses (128). The ILO encyclopaedia acknowledges that traumatic injuries, such as amputations, are more likely to occur in small establishments (94).

5.4.3 *Interventions, small businesses, and traumatic injury prevention*

Since the paper on the status of occupational health interventions by Goldenhar and Schulte in 1994 (129), the number of intervention studies has increased, and the overall quality has improved. Numerous reviews have been published in the past few years in which the basic methodological principles for intervention studies in occupational health are explained and prudently discussed (130). However, studies that apply a randomized controlled design to evaluate injury prevention interventions in small businesses remain sparse.

Mancini and co-workers conducted an observational study that evaluated the effectiveness of interventions for preventing ocular injuries among metal-workers and found that a carefully coordinated, extensive, multicomponent intervention will have a sustained effect on reducing injuries (131). However, Mancini and co-workers conceded that randomized controlled studies would provide more conclusive evidence on the effectiveness of such interventions (131). The dearth of randomized controlled studies is also acknowledged in the review of effective work-related injury prevention interventions by Rivara and Thompson (91). The absence of randomized controlled studies was reiterated by Lehtola and co-workers in a recent review of injury prevention interventions in the construction sector (54). Breslin and co-workers performed a review of effective occupational health interventions among small businesses and found that many low-quality studies did not include a concurrent control group, which is necessary to evaluate effectiveness (55). They further suggested that intervention studies could be improved by increasing the number of small businesses recruited because many studies often apply the case-study approach by recruiting only one or a few businesses. Breslin and co-workers found only one high-quality intervention effectiveness study that applied a randomized controlled design, provided explicit sample sizes, had a long follow-up period, and was able to demonstrate some effectiveness of the intervention (55). Lipscomb and co-workers in a systematic review of interventions to prevent eye injuries at workplaces state that There is limited scientific literature about the effectiveness of eye injury prevention interventions. Moreover, there is a need for systematic evaluation of interventions designed to prevent eye injuries and to change the overall safety culture (132).

A systematic review of injury prevention interventions by Lehtola et al. endorsed a multifaceted occupational health intervention that includes educational, engineering, and behavioural components (54). Interventions that target both management and workers were reported to be effective in a systematic review of injury prevention interventions in the construction sector (133). In this context, the role of safety committees is compelling. Previous studies have documented safety improvements in workplaces that establish safety committees (133,134). In a longitudinal study of 637 workplaces in Canada, Lewchuk and co-workers showed that safety committees helped reduce the number of lost-time injury claims made by workers (135).

An often neglected but critical component of occupational health intervention research involves issues related to worker-management relations (136). Management and workers participate in a dynamic interaction with exchanges of ideas and information. This interaction plays an important role in determining the nature and success of workplace health and safety programs (137-140). A study of manufacturing businesses by Geldart and co-workers showed that manager and worker participation in occupational health initiatives characterized safer workplaces and lower injury rates (141). Workplaces that demonstrate “higher engagement” from workers and management may yield greater occupational health benefits. Higher engagement in this context implies the inclusion of hands-on training components as opposed to passive reception of lectures or presentations (142).

5.4.4 Surveillance of work-related amputations

Surveillance is a vital tool for the recognition and prevention of work-related injuries and disease. The identification of cases can benefit individuals, their immediate co-workers, workers throughout the industry, and people exposed to implicated causal factors in other settings (143). Our understanding of the magnitude of work-related traumatic amputations and how to prevent them effectively remains inadequate, in part because of tenuous surveillance mechanisms.

In the United States, epidemiological research and surveillance data on work-related amputations have been available for about 20 years (98,144,145). The US BLS in 2008 reported a national incidence of amputations of 7 per 100,000 workers. However, data from Michigan suggested significant underreporting of work-related amputations. Largo et al. reported that the US BLS estimates for amputations were 77% lower than the estimates found in Michigan (146). Recent data from Illinois and Washington illustrated that the underreporting of work-related amputations remains a challenge in the United States (80, 83). Despite the underreporting, work-related amputation is a surveillance indicator of choice for traumatic work-related injuries endorsed by the Council of State and Territorial Epidemiologists in the United States (147). Thus, surveillance data on amputations at work in the United States, although incomplete, are available for epidemiological analysis and may contribute to the development of preventive strategies and policies.

In contrast, work-related amputations remain a relatively unexplored area in epidemiological research and surveillance in Norway. In fact, no epidemiological study of amputations at work can be found. Gravseth and co-workers compared work-related injury surveillance data from a hospital in Oslo with data recorded at the NLIA’s Oslo bureau and found that only 28% of the serious injuries reported at the hospital were recorded by the NLIA. This study did not include amputations specifically, but the investigation underscored the tenuous nature of traumatic injury surveillance systems in Norway (148). The Norwegian government recently published a national strategy for injury prevention. Among others, preventing work-related injuries was indicated as an area of interest (149). The strategy acknowledged the weaknesses in the surveillance infrastructure and emphasized the need for reliable data to develop injury prevention policies (149).

Robust surveillance systems remain critical for the meticulous application of a public health approach to injury prevention because only precise documentation of the nature and true magnitude of a problem (e.g., amputations) will justify resource allocation, regulatory intervention, and other remedial actions.

5.4.5 Risk of work-related amputations in the manufacturing sector

In terms of trade sectors, manufacturing is a documented risk factor for work-related amputations globally (75, 79, 97). This is perhaps because of the overrepresentation of hazardous machines, such as saws, presses, and shears, within manufacturing (100,150, 151). In the United States, the incidence in the manufacturing sector is 20 per 100,000 workers (96). Data from ANPIC and NLIA also suggest that the largest number of amputations in Norway occurred in the manufacturing sector (10,152).

In summary, this study addressed several gaps in the existing knowledge base concerning the prevention of traumatic work-related injuries. First, this study develops and evaluates an intervention to reduce work-related amputations and other traumatic injuries attributed to hazardous machines based on a study in Minnesota. Second, this study provides an epidemiological profile of work-related amputations in Norway and highlights the need for a robust surveillance infrastructure for work-related amputations in Norway. The goal is to provide policy makers and occupational health professional’s empirical evidence to make informed decisions while devising injury prevention strategies and policies.

6. AIMS

General aim of this study is:

To develop effective preventive interventions and enhance the surveillance mechanisms, to reduce the risk of work-related upper-extremity amputations.

Specific aims of the papers are

1. To assess the risk of injuries caused by machine-related hazards in small manufacturing businesses in Minnesota
2. To implement and evaluate the effectiveness of an injury-prevention intervention targeted toward worker-management and management-only groups in small manufacturing businesses
3. To characterize the epidemiological profile of work-related upper-extremity amputations in Norway based on data from 2007
4. To estimate the total number of work-related upper-extremity amputations in the Norwegian manufacturing industry over a 10-year period using a capture-recapture method

7. STUDY IN MINNESOTA

The study in Minnesota is based on findings from the Minnesota Sentinel Event Notification System for Occupational Risks (SENSOR). SENSOR was an 8-year-long study (1992-2000) funded by the National Institute of Occupational Safety and Health (NIOSH) and led by David Parker at the Minnesota Department of Health (85,98). Principal investigator David Parker, MD, MPH, has been working on the prevention and surveillance of work-related injuries and diseases since the early 1980s. The SENSOR study found that a significant number of amputations were caused by hazardous machines, and the absence of machine guards was an implicating factor.

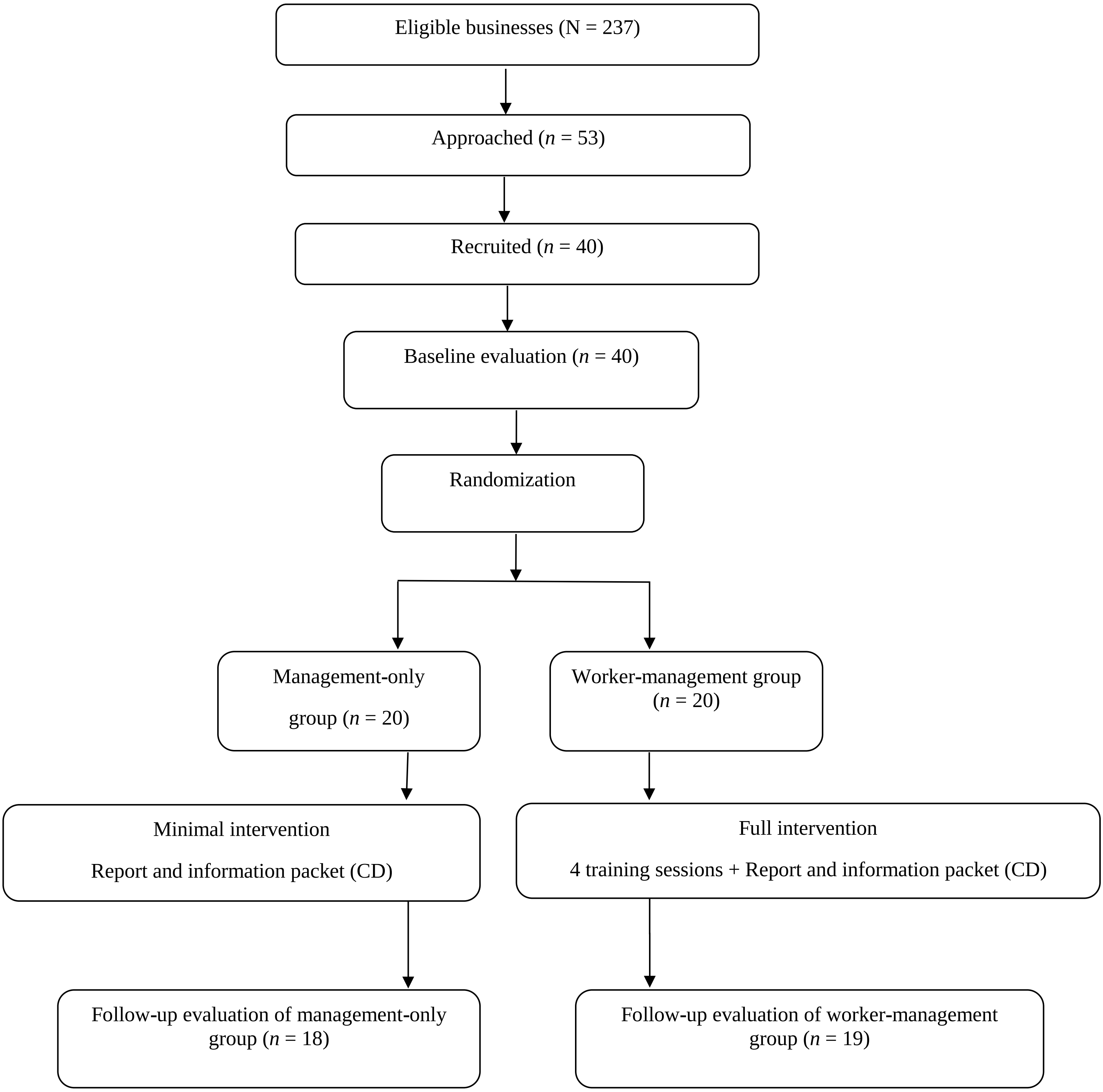
The author of this thesis worked as a physician at emergency care units in Bombay, India (1998-1999), treating traumatic injuries. Subsequently, the author was more drawn toward the field of preventive medicine and public health with an interest in the field prevention of diseases and injuries by applying a public health approach. Thereafter, the author completed 1 ½ years of residency in preventive and social medicine at Grant Medical College, Bombay and was involved in several occupational health projects. The interest in the public health approach led the author to pursue a Masters in Public Health at the School of Public Health at the University of Minnesota.

David Parker was an adjunct faculty at the School of Public Health, University of Minnesota, and the instructor of a public health course that the author attended. The author subsequently explored opportunities for collaboration with David Parker to work on public health projects. In due course, David Parker informed the author about a grant awarded by NIOSH to conduct a large randomized controlled intervention study with the aim of preventing amputations in small metal fabrication businesses in Minnesota (2002-2008). The author served as a research program manager for this study and took part in writing several papers (Appendix Chapter 11.5) either as co-author and author, and the first two papers included in this thesis is based on the aforementioned study.

7.1 Materials and Methods

The Minnesota study was designed as a randomized controlled intervention with baseline measures, intervention application, and follow-up evaluation.

7.1.1 Design



7.1.2 Inclusion criteria and recruitment

The baseline evaluations included data collected from 40 small metal-fabrication businesses in Minnesota. Metal fabrication facilities from the Twin Cities (Minneapolis-St. Paul) metropolitan area were eligible for study participation if they met the following criteria at the time of recruitment (2003-2004):

1. Total employment of 5-100 workers at the study site (only one site of a multi-site company could participate);

2. At least 10 metal fabrication machines from a list of 23 different machines from five machine categories: (a) milling, drilling, boring; (b) cutting, shearing, sawing; (c) presses; (d) rolling, bending; (e) sanding, grinding;
3. In business for at least 1 year prior to recruitment and located within approximately 50 miles of the study office (Minneapolis); and
4. In a trade sector within at least one of the 13 identified SIC codes that comprise metal fabrication trades.

These criteria were met by 237 businesses. Businesses were recruited to the study by the Principal Investigator (David Parker) primarily through personal introduction from union leaders, insurance companies, business employees, and business owners. Businesses were also identified using business directories and meetings with metal fabrication trade groups. After receiving a letter of introduction, business representatives were contacted by telephone for an appointment with the owner or a manager. At the initial meeting, demographic data were obtained, including the types and number of machines, union status, and number of employees, managers, and non-English-speaking workers. The number of employees in the participating business was reassessed at the baseline evaluation.

7.1.3 Collection of data

The evaluation team (including the author) visited 40 different businesses recruited in this study and collected data on randomly selected machines with regard to their compliance to safety standards from a best practices perspective. The checklists for collecting these data were developed in a consensus conference of researchers, OSHA representatives, union representatives, owners, safety engineers, and industrial hygienists. Checklists were developed for 23 different hazardous machines identified in the consensus conference.

Checklists were designed using a combination of engineering and policy criteria for machine safety (153). The criteria included the following: guarding and/or devices at the point of operation; guarding of moving parts (e.g., gears, pulleys); adequate labelling of machinery (e.g., model, electrical data plate); presence of emergency stop; slip-free, uncluttered, and adequately lit work area; adequate electrical wiring (e.g., no worn or damaged wires); and clear lockout/tagout procedures (154,155).

The items on the checklists were assigned a priority ranking of high, medium, or low based on two factors: (*i*) general consensus among the experts that an injury might occur if a safety feature (item) was missing or not properly functioning on a machine, and (*ii*) the potential severity of the injury. Thus, high-priority items were those that if absent were likely to cause severe injuries. Medium-priority items were those that were less likely to cause injuries, or injury was unlikely to occur but might be less severe if it occurred. Low-priority items were those that required full compliance with OSHA or ANSI standards. These checklists were tested for inter-rater reliability. Overall, the kappa statistic ranged from 0.57 to 0.84, indicating good to very good concordance between the raters (153). Additionally, a 25-item shop safety checklist was used to evaluate three aspects of overall shop safety: general business environment (e.g., lighting, safety bulletin board), administrative and management policies (e.g., safety committee meeting minutes, maintenance of OSHA 300 log), and employee-related work practices (e.g., use of protective eye wear, documentation of employee training).

A sample machine checklist and shop checklist are included in the Appendix (Chapters 11.1 and 11.2). The data were collected and optically scanned into a Microsoft Access database.

7.1.4 Sampling of machines

Machines were selected based on a sampling strategy that provided a proportional sample of machines in each shop based on the distribution of the types of machine in each business. Machines were then randomly sampled based on their relative number in each of the five categories. For example, if a business had 100 machines with 50 in the milling and drilling category, then 50% (12 of 25) were randomly selected from this category of machines. The remaining 13 were randomly selected in proportion to the number in each category.

We evaluated a minimum of 10 and maximum of 25 machines in each business. If a business had fewer than 25 machines, then all qualifying machines were included in the sample. Each selected machine was evaluated with the appropriate machine safety checklist. Items received a score of “1” if the item was present and considered adequate and “0” if it was not present or inadequate. Items that were not assessable were assigned a missing value for the purpose of data analysis. For example, the electrical data plate and model of a machine were often present but not visible (i.e., in a dangerous location not at eye level). To compute a machine safety score, each checklist item (e.g., barrier guard) was assigned a priority of one (high; e.g., emergency stops), two (medium; e.g., strain relief on electrical wires), or three (low; e.g., yellow colour on the guards) to reflect both the probability and severity of injury (153).

7.1.5 Measures

Each business received a machine safety score based on the checklists that were used to evaluate the machines. Additionally, each business received a score based on general health and safety compliance in the facility. The measures were combined such that each participating business obtained a composite safety score.

1. Machine safety score (average of all machines evaluated)
2. Shop Safety score (shop safety checklist)
3. Composite safety score (A+B)

7.1.6 Intervention description

The intervention developed for this study included several components, including:

1. Hazard identification and control (e.g., recommendations concerning machine guarding)
2. Administrative programs (e.g., lockout/tagout programs)
3. Safety training (e.g., hazard recognition, lockout/tagout procedures)

A peer trainer delivered a summary report of machine and shop safety evaluations to the managers of the businesses approximately 2 weeks after the first evaluation. Reports delineated machine-related hazards and prioritized changes that were needed for individual machines and administrative problems. Each business also received a CD that contained machine and shop safety checklists, documents and resources, copies of machine checklists for 23 different metal-fabrication machines, a sample written lockout/tagout program, and machine-safety training materials.

The businesses assigned to the **worker-management group** were provided the reports, a CD, and four training sessions. The businesses assigned to the **management-only group** were provided only the reports and a CD. Each safety committee from the management-worker group participated in four 1-hour educational sessions that were offered by a peer educator who was an experienced machinist trained in machine safety. If not already in existence, businesses in the worker-management group were requested to identify appropriate managers and workers to establish a safety committee.

7.1.7 Statistical analysis

Each business received a machine score (mean of all machine checklists) and shop safety score. The analysis included the computation of means, standard deviations, and chi-squares. We used linear regression to explore the relationship between machine scores and shop safety scores and influence of demographic variables on each of these outcome measures. We used linear mixed models to examine the relationship between machine scores and machine and business characteristics. The analysis was performed using Statistical Analysis Software.

7.1.8 Ethics

All of the data collection methods and surveys were reviewed and approved by the Park Nicollet Health Services and University of Minnesota Institutional Review Boards.

7.2 Main results

7.1.1 Paper I: Profile of machine safety in small metal fabrication businesses

Forty businesses were evaluated in this baseline study. A total of 824 machines were assessed. On average, the businesses had 37 machines, whereas 15 of the 40 businesses had fewer than 25 machines. We found that 55% of the items that addressed machine guarding were present, 39% of the items were absent, and 6% could not be assessed. Overall, 60%, 54%, and 51% of the high-, medium-, and low-priority items were present on these 824 machines, respectively. Businesses with 25 or more workers received higher machine safety scores than businesses with fewer than 25 workers. The average shop safety score was 65%. Businesses with safety committees had a better shop safety score than businesses without safety committees. The average composite score was 62%. The presence of a safety committee positively influenced the composite safety scores. The presence of lockout/tagout programs increased with business size. The presence or absence of lockout/tag out training records resulted in high composite scores.

7.1.2 Paper II: A randomized, controlled intervention of machine guarding and related safety programs in small metal-fabrication businesses

Of the 40 businesses recruited in the study, 37 participated in follow-up evaluation. Two (one in each group) had gone out of business, and one in the management-only group declined to participate. Therefore, we had an overall follow-up participation rate of 97% (37/38). We found no differences between the two groups in either the machine or shop safety score. The baseline mean machine score was 63% in the worker-management group and 64% in the management-only group. The mean shop safety scores were 66% and 64% for the worker-management and management-only groups, respectively. All of the scores at the baseline evaluation indicated that machine guarding and related safety programs were frequently missing or inadequate. Mean machine scores significantly improved from baseline to follow-up by a similar amount (4-5 points) in each of the groups ($p < 0.001$). Similar changes were also observed in shop safety scores in both groups but were not statistically significant. We did not observe differences in the magnitude of change in either outcome measure between the two groups. Similarities existed between the two groups when data were stratified by safety committee, union status, and number of employees.

7.3 Discussion

7.3.1 Paper I: Profile of machine safety in small metal fabrication businesses

At baseline, 40% of the high-priority items that could provide protective effects for workers against traumatic injuries, such as amputations, were absent from the machines. These items included emergency stops, barrier guards, and lockout/tagout procedures. These findings are consistent with those reported by Gardner and co-workers and Khanzadeh et al. (156,157). Our findings indicate that larger businesses were more likely to have an effective safety infrastructure. Specifically, safety committees were associated with higher levels of shop and machine safety. Similar findings among 127 manufacturing sites were reported by Boden and co-workers (158).

Small businesses are particularly vulnerable to injuries, and increased risk is often attributable to a lack of resources, lack of knowledge on the part of workers, lack of worker autonomy, lack of unionization, financial pressures, and resentment of the regulatory environment. Eakin et al. claimed that regulatory exemptions, subcontracting, the changing character of small business, inspection constraints, and competing institutional accountability are some of the factors that make small businesses more vulnerable to higher injury risks (159).

A safety committee is mandatory in businesses with more than 25 workers in Minnesota. Of the 21 businesses recruited in this study with 25 or more workers, only 30% had a safety committee. Businesses with 25 or more employees and safety committees tended to have higher machine, shop safety, and composite scores. This finding is comparable to the results reported by Reilly and co-workers in a study of British workplaces, where workplaces with safety committees had a 50% lower injury rate than those without safety committees (132).

Our study also found dissonance in the understanding and implementation of safety and health programs. Although 60% of the businesses were able to furnish training records concerning lockout/tagout, only 13% had established a lockout/tagout program. Our baseline results indicated that the businesses that implemented machine guarding programs, provided adequate safety equipment, provided safety training, and implemented good record-keeping practices exhibited high levels of machine safety.

The difficult aspect of measuring machine guarding and machine safety is partially attributable to a lack of a single coherent standard to evaluate machines. We developed standardized checklists to evaluate machine safety. We applied methods utilized by Jones, La Montagne, and co-workers that enabled empirical ratings of hazards and safety (160,161).

The checklists gauged the level of safety for each machine without subjective opinions about their potential to cause injury. Each checklist was a reliable and calibrated tool for measuring the risk of traumatic injuries, such as amputations. Additionally, checklists were part of the intervention and provided as hands-on training material to both groups. The checklists were thus a tool for data collection, method for prioritizing machine hazards, and means to provide training to workers and managers.

A major limitation of the checklists was their inability to link safety scores to injury data. Data on the relationship between the level of machine safety and amputations are lacking. In a study of work-related amputations, Boyle and co-workers reported that the absence of machine guards is a persistent theme at the time of injury (84). The prioritization of items on a machine as high, medium, and low should ideally be based on surveillance data. However, in the absence of injury data, the study utilized a panel of experts by organizing a consensus conference to prioritize hazardous items on the machines.

This study had other limitations. First, the age of most of the machines was unavailable. An older machine is more difficult to retrofit with safety features and guards. This relationship between the age of a machine and guarding was also suggested by Gardner (157). Second, 23 of the most commonly used and hazardous non-portable machines in the metal fabrication industry were included in this study. Laser and plasma cutting tools and computerized numeric coding machines were excluded because of their complexity. Third, recruiting businesses was difficult. Some owners were reluctant to speak to us. The most common reason offered by non-participating businesses was that they did not have the time or that their health and safety needs were attended adequately by an insurance risk consultant who provided safety audits. The refusal to participate by many owners could be because this was a government-funded research study, and the small-business community harbours scepticism toward government-funded initiatives. We therefore used referrals from our advisory board, other owners, and a trade union representative to facilitate recruitment. However, non-participants (i.e., those who were contacted and eligible but did not participate) were similar to participants with regard to SIC code, number of employees, and yearly revenue.

7.3.2 Paper II: A randomized, controlled intervention of machine guarding and related safety programs in small metal-fabrication businesses

The overall findings of this study indicate that exposure to hazardous machines can be reduced and that machine-related hazards remain problematic in metal-fabrication trades. Businesses that added a safety committee and businesses that had low baseline machine and shop safety scores showed the greatest improvement during the intervention period. The magnitude of change seen in shop safety scores indicates the apparent ease with which important administrative programs were remedied. For example, we noted a 20% increase in the number of businesses with safety committees, with scores that increased from 50% to 70% ($p = 0.05$). These changes were unlikely artefacts or a regression to the mean. Better-performing businesses did not show a worsening of their scores at follow-up. Quality-control procedures assured adherence to the study protocols. Process evaluation data support our belief about the importance of safety committees.

Our findings are also supported by work with small enterprises in South Asia. Kogi used the active engagement of management and employees to improve the health and safety of workers within small enterprises (162,163). The importance of active worker engagement in health and safety in small-scale enterprises was demonstrated in a study of nine small-scale enterprises in the Philippines using methods defined by the ILO Work Improvement in Small Enterprises (WISE) program. Our methods were similar to those used by the WISE program (164).

Although the issue of unionization was not addressed in detail in this particular study, the potential benefits offered by safety committees may be tempered by the absence of unionization in businesses (165-167). Recent OECD data indicate that the trade union density in the United States is approximately 11% (16% in Minnesota) compared with 54% in Norway, which is an interesting finding in the context of the effectiveness of safety committees in reducing hazards (168).

This study utilized randomization as a method to assign businesses to the two groups (worker-management and management-only) after the baseline evaluation. Moreover, the evaluators who assessed the machines and businesses were blinded to the business group assignments at both baseline and follow-up. Regardless, no true non-intervention group was formed, and this study had only minimal-and full-intervention groups. We believed that we needed to at least inform the owners of the health and safety hazards identified in each participating business and provide a blueprint for remedial action. We therefore chose a minimal intervention group, in which the management was informed about potential health and safety hazards in their businesses. In the worker-management group, the management was provided the report, and a safety committee that comprised workers and managers was provided four training sessions that included a hands-on component and discussions of the evaluation report.

We cannot definitively say that the changes measured at follow-up were solely the result of our intervention because no differences were seen between the two intervention groups. However, we believe that these changes were likely the result of our intervention for several reasons: (1) they were consistently found in some subgroups; (2) shop evaluation was carefully monitored, and a 25% sample was randomly selected for quality control; and (3) machines were randomly selected at each visit to ensure an unbiased estimate of our primary measure.

A randomized controlled design is difficult to implement when testing the effectiveness of occupational health interventions because of practical, legal, and ethical constraints (91). Lipscomb has suggested that observational studies, despite their limitations, might be a useful alternative to test the effectiveness of occupational health interventions (169,170).

8. STUDY IN NORWAY

8.1 Materials and methods

This part of the thesis includes two studies. First, a descriptive study characterized the epidemiology of work-related amputations in Norway based on injury data from 2007. Second, a retrospective study was conducted to estimate the total number of work-related amputations. The descriptive study provided an epidemiological profile of work-related amputations in Norway, whereas the retrospective study applied a capture-recapture method to estimate the total number of upper-extremity work-related amputations in the Norwegian manufacturing industries.

8.1.1 Design

The descriptive analysis was based on cross-sectional data on work-related upper-extremity amputations found in the NLIA Registry of Work-Related Injuries (RWI) in 2007.

Capture-recapture methods used for the estimation of amputations in the manufacturing industry were pioneered in ecology and derive their name from censuses of wildlife, in which several animals are captured, marked, released, and subject to recapture. In epidemiology, the technique examines the degree of overlap between two or more sources to estimate the total size of the population. Studies that attempt to ascertain all cases of a given health outcome in a population should use this method to estimate the number of missing cases (171,172).

8.1.2 Databases

Two databases were used in the Norwegian part of the study: RWI and ANPIC.

The Norwegian Labour Inspection Authority's Registry of Work-Related Injuries (RWI)

Employers are legally mandated to report compensable work-related injuries and fatalities to the Norwegian Labour and Welfare Administration (NLWA). If the employer fails to report the injury, then the worker may report the injury to the NLWA. Injury reports are sent using a standardized reporting format. A copy of the injury report is sent by the NLWA to the NLIA. Injury data are manually entered at the NLIA into the RWI.

Each case includes a unique 11-digit personal identification number that is designated to legal residents in Norway. The RWI is the basis for the national and international reporting of work-related injuries. The primary purpose of reporting to the NLWA is to ensure that the state-financed workers' compensation system has registered the incident. State-financed insurance pays for some of the expenses related to the injury, such as medical treatment, and full sickness benefits. State-financed insurance is an option and not an obligation for the self-employed. The NLIA registry was used for the both the descriptive and capture-recapture studies.

Association of Norwegian Private Insurance Companies Registry of Occupational Injuries (ANPIC)

Employer-financed insurance provides compensation to injured workers above and beyond state-financed workers' compensation. Insurance companies pay for expenses, such as future loss of income and expected costs that may be incurred because of the injury. All employers in Norway are obligated to provide insurance coverage for their workers. This does not apply to self-employed workers. The injured worker must file the compensation claim with the employer's insurance company. Private insurance companies in turn send injury data to ANPIC. These claims data are the basis for the ANPIC Registry of Occupational Injuries. The ANPIC registry consists of more serious injuries, such as amputations, because the minimum claim that a worker can file with the insurance companies is NOK 500 (USD$90). This registry also includes the 11-digit personal identification number. This database was used only for the capture-recapture study.

8.1.3 Measures

For the descriptive study, we computed incidence rates based on the number of amputations and employment data by age, gender, business size, and trade sector. The employment data were obtained from Statistics Norway.

To estimate the number of amputations based on a capture-recapture method (Figure 1), we chose to apply the Chapman Estimator for a two-source capture-recapture study (173). The Chapman estimator is expressed as the following:

$N_{chapman} = [(c_1 + 1)\ (c_2 + 1) / m+1] - 1$

c_1 = number of cases captured in the NLIA registry

c_2 = number of cases captured in the ANPIC registry

m = number of cases captured in both c_1 and c_2

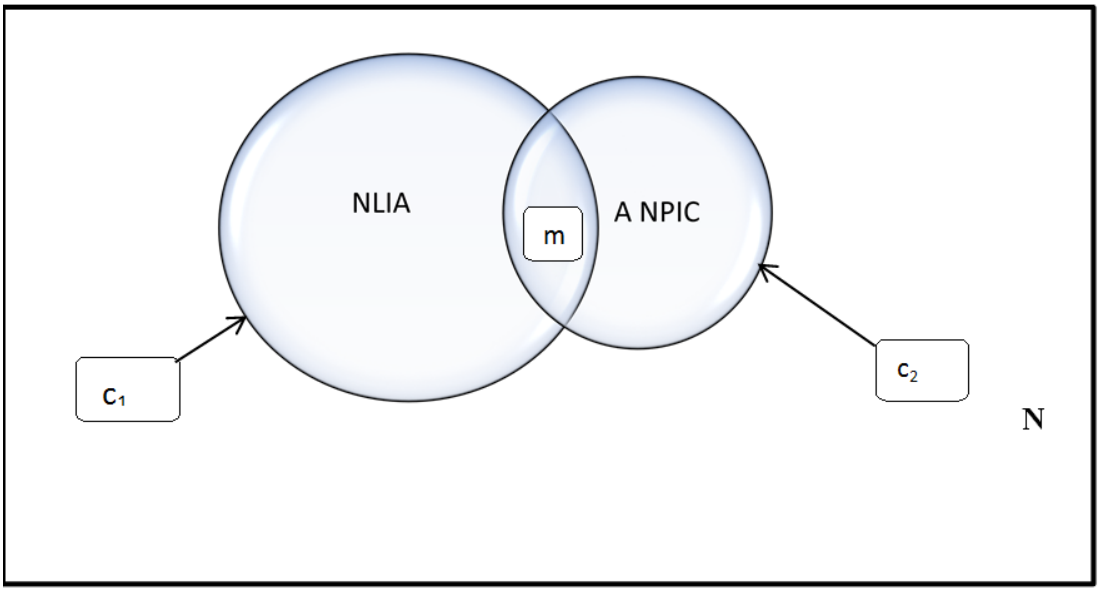
N = estimate of total number of cases

The variance for the estimators was calculated to compute the confidence intervals.

$\text{Variance} = (c_1+1)\ (c_2+1)\ (c_1-m)\ (c_2-m) / (m+1)^2\ (m+2)$

$95\%\ CI = N_{chapman} \pm 1.96\sqrt{\text{Variance}}$

Figure 1. Capture-recapture method that shows the two sources (c_1, c_2), overlap of cases (m), and estimate of total number of cases (N).



8.1.4 Statistical analysis

To characterize the epidemiological distribution of amputations in Norway, we performed a descriptive analysis of the injury data by age, gender, business size, trade sector, time of injury, weekday of injury, and month of injury for the year 2007. We computed the incidence rates by age, gender, business size, and trade sector.

For the capture-recapture study, data for upper-extremity amputations were extracted from the two databases (RWI and ANPIC) for all of the trade sectors, including manufacturing. Cases with the trade sector coded as manufacturing were included for further analysis. Cases from the two databases were matched using a unique 11-digit personal identification number. The analysis was performed separately for each year. Moreover, we checked for unmatched cases from ANPIC for matches with data from RWI for all of the other years. For example, all of the unmatched cases from ANPIC in 2007 were checked for matches in the RWI data from 1997-2006. All unmatched cases in the ANPIC registry were checked for matches with amputation cases available from the RWI from all trade sectors. This process yielded seven additional amputation cases across the 10-year period. Although these seven cases did not match the trade sector (i.e., manufacturing), they matched the birth date, gender, unique identification number, and year of injury across the two databases. These seven cases were included in the analysis.

Figure 1 above illustrates the capture-recapture method, in which c_1 and c_2 are the cases found in the NLIA and ANPIC registries, respectively, and m is the number of matched cases found in both registries. N is the estimate of the total number of cases based on c_1, c_2, and m. Based on the estimates, we also calculated the estimate for the undercounting of cases to the NLIAs RWI. We computed the annual incidence of amputations in the manufacturing industry based on the estimated number of amputations per year and number of workers employed in manufacturing in that year. We used Microsoft Excel, SPSS, and Open-Epi software for these analyses (174).

8.1.5 Ethics

All of the data collection procedures were reviewed and approved by the Central-Norway Committee for Medical and Health Research Ethics.

8.2 Main results

8.2.1 Paper III: Work-related upper-extremity amputations in Norway

For 2007, of the 227 injuries recorded in the RWI as a lost body part, 149 (66%) were upper-extremity amputations. These cases were reported by 149 separate businesses. The overall incidence of upper-extremity amputations was 6 per 100,000 workers. Men accounted for 87% of the cases (upper-extremity amputations). Incidence rates for upper-extremity amputations were 10 and 2 per 100,000 among male and female workers, respectively ($p < 0.05$). Workers aged 20-24 years had a higher incidence rate for upper-extremity amputations (cases) than workers in the other age groups. The majority of the cases were found in businesses with 49 or fewer employees. The incidence was highest in businesses with 1-9 employees. A higher incidence was found in manufacturing (21 per 100,000 workers) and construction (20 per 100,000 workers) compared with the other trade sectors. Overall, wood-working and metal fabrication together with food production accounted for 71% of the cases. Fingers accounted for 95% of the upper-extremity amputation cases. Hand amputations accounted for 5% of the cases.

8.2.2 Paper IV: Work-related amputations in the Norwegian manufacturing sector: A 10-year retrospective study based on two-source capture-recapture method

For the years 1998-2007, the RWI had 663 amputation cases, and the ANPIC registry had 196 cases. Males comprised 83% and 82% of the cases in the NLIA and ANPIC registries, respectively. A total of 130 cases were matched across both registries for the 10-year period (i.e., 130 cases were found in both registries). Of these 130 matched cases, 88% were male. Finger amputations comprised 93% of the cases found in the RWI and 90% in the ANPIC registry. Only 7% of all of the cases in the RWI were complete arm or hand amputations, whereas 10% of all of the cases in the ANPIC registry were either arms or hands. Finger amputations comprised 95% of matched cases, and hand and arm amputations comprised the remaining 5% of matched cases. The results indicate that the overall numbers of amputations per year steadily decreased from 1998 to 2007. This decrease, however, was more pronounced in the period 2003-2007.

The largest Chapman estimate was 183 cases in 1998, and the least number of estimated cases was 57 in 2007. We estimated an annual incidence rate that ranged from 21 to 62 per 100,000 workers during the study period. Underreporting varied from 16% to 58% during the study period.

8.3 Discussion

8.3.1 Paper III: Work-related upper-extremity amputations in Norway

Data from this study suggest that workers who were male, young, and employed in small-businesses and the manufacturing sector were at greater risk for upper-extremity amputations than other workers. Our understanding of the etiology of amputations in general remains constrained because hazardous exposure data and their link to specific work that leads to amputations are lacking. Of particular importance for the prevention of amputations is an understanding of the presence or absence of machine guarding technology, such as barriers at the point of operation, emergency stops, and other means to prevent worker contact with moving parts.

The estimated incidence rate of 6 per 100,000 workers for upper-extremity amputations in Norway is comparable to a rate of 9 per 100,000 workers in Finland and 15 per 100,000 workers in Sweden. Variations in the annual incidence rates between these three Nordic countries may be partially explained by underreporting. The underreporting of work-related injuries is a universal phenomenon that undermines the findings of registry-based studies.

Consistent with our findings, a higher incidence of upper-extremity amputations was also observed by Jin and co-workers among young workers compared with older workers in their study of hospitalized workers in China who sustained traumatic work-related hand injuries (6). Furthermore, several studies have documented a higher incidence of work-related injuries in smaller *vs*. larger businesses (175,176). Our data show that workers in micro businesses (< 10 employees) and small businesses (< 50 employees) are more likely to sustain upper-extremity amputations than workers in larger businesses.

Manufacturing employs approximately 11% of the Norwegian workforce but accounts for 36% of all upper-extremity amputations. Comparable results have been reported in other studies, indicating that manufacturing remains a high-hazard sector for work-related amputations (79,177).

The primary limitation of this study was the undercounting of the number of amputations. Several reasons may explain this undercounting. First, many self-employed workers fail to report injuries because they lack the incentive to report injuries to authorities. Self-employed workers do not qualify for state-funded compensation that requires the reporting of injuries. Many agricultural workers, for example, are self-employed, and the surveillance system most likely fails to capture amputations from this sector. Second, immigrant workers are a group that most likely does not report injuries to state-funded systems, among others, because of precarious work conditions (178,179). Third, employers' lack of awareness concerning the obligatory reporting of work-related injuries in Norway has been suggested by Gravseth et al. (148). Finally, data are sent from the NLWA to NLIA as paper copies, and all of the data are unlikely to be registered at the NLIA. This is an incidental finding of this study, which remains a subject for future investigation.

The data utilized in this study also lacked information on hazardous machinery and tools that are causal factors that lead to an amputation; therefore, our understanding of the etiology of amputations based on these data remains constrained. Furthermore, the registry data do not include information on the number of days away from work or the extent of the injury (e.g., location of amputations on the finger, number of digits), thereby limiting our ability to comment on the severity of the injury and develop targeted preventive strategies. RWI is based on data that are reported on NLWA compensation forms and lacks information that may be valuable for prevention (e.g., machines or tools that caused the injury).

Despite these limitations, the results of this study are consistent with the literature on this topic, which strengthen our conclusions. These findings support the need to improve the surveillance of traumatic injuries in Norway and point to the generally poor reporting of such injuries globally.

8.3.2 Paper IV: Work-related amputations in the Norwegian manufacturing sector: A 10-year retrospective study based on two-source capture-recapture method

The estimated number of amputations within the manufacturing sector indicates that the RWI significantly undercounts the number of cases. The undercounting in the RWI based on the Chapman estimates ranged from 15% to 58%. This is consistent with previous Norwegian studies that indicated an undercounting of 56% to 44% for serious and fatal work-related injuries, respectively, reported to the NLIA (148,180).

Several reasons may explain the undercounting of amputations in the RWI. The most common reason is employers' failure to comply with the obligatory reporting of work-related injuries to the NLWA. The NLIA inspection data indicate that employers' compliance with the law in terms of the reporting and registration of work-related injuries is rarely enforced and not formally monitored. In a study of serious work-related injuries in Norway, Gravseth and co-workers attributed underreporting to employers' lack of awareness regarding the obligatory reporting of work-related injuries (148).

Some employers may wilfully choose not to report an injury to governmental authorities because they perceive that reporting may result in regulatory inspections and possible citations. Furthermore, the cost of insurance premiums incurred by the employer may increase following a compensation claim. Non-compliant employers may intentionally keep their workers uninformed about filing a compensation claim with insurance companies.

Self-employed workers in Norway may not have an incentive to report to either the NLWA or ANPIC. Self-employed workers are not covered by either the state-financed insurance program or private insurance unless they have voluntarily agreed to participate. Thus, injuries sustained by self-employed workers may not show up in the ANPIC or RWI registries. Finally, some of the undercounting of cases in the RWI may be attributable to imperfect dataflow and reporting routines between the NLWA and NLIA and remains a subject of investigation.

Our findings suggest a decline in the number and incidence rates of upper-extremity amputations in manufacturing over the 10-year study period. Several reasons may explain this decline. First, during the study period, the number of workers in the Norwegian manufacturing sector decreased by 9%. Second, the decline in recent years (2003-2007) may be explained by a time lag in reporting. Both NLIA and ANPIC concede that the data for a particular year are complete after 2 years have elapsed. The decrease in the number of cases is more pronounced from 2003 onward. This recent decline in the registered number of cases could potentially be ascribed to the organizational restructuring of NLIA and NLWA during these years, which may have impacted reporting routines. Third, despite the decrease in employment within manufacturing, the employment rates for Eastern European immigrant workers within manufacturing have exponentially increased since 2003 because Norway opened its labour market to the new Eastern European member states. This study did not account for all immigrant workers in Norway because not all immigrant workers are assigned an 11-digit identification number. The absence of data on short-term immigrant workers and those engaged in precarious work are likely to suppress the amputation estimates.

Manufacturing processes in Norway may have improved safety levels in general, thereby decreasing the number of injuries. However, given the extent of underreporting documented in this study and other Norwegian studies, the decline may be deceptive in terms of characterizing the reduction of the risk of amputations in manufacturing (148, 180,181).

The two-source capture-recapture method applied in this study has been extensively employed in epidemiology to estimate the total number of cases (182-185). The first use of capture-recapture methods in public health was Sekar and Deming's estimation of the completeness of birth and death registers in 1949 in India (186). Personal identifiers, such as identification numbers and/or names, were used as marks or tags. The capture-recapture method was further refined in the 1950s by Chapman, who suggested an adjustment of the capture-recapture estimate to reduce small-sample bias. He developed what is known as Chapman's unbiased estimator, which was utilized in this study (187).

The capture-recapture method relies on the assumptions that the two sources are independent, the population is closed, and cases are correctly identified (173). The assumption of independence is rarely met in a two-source capture-recapture analysis (173,188,189). The two sources utilized in this study were unlikely to be completely independent. First, compliant employers who report to the NLWA are more likely than non-compliant employers to counsel workers to file a compensation claim with insurers. Second, during claims processing, the NLWA may inform workers about their right to file a compensation claim with their employer's insurance company. This would result in an increased probability of cases being recaptured with the ANPIC registry if they have already been captured by the NLIA, introducing a bias in our Chapman estimate because of "positive dependence" (190,191). Positive dependence would yield a conservative annual estimate of the number of upper-extremity amputations (i.e., underestimate the number of cases). The second assumption, a closed population, is met as the capture (c_1) and recapture (c_2) of cases comes from the same pool of cases, which is "closed" in terms of residency (Norway), trade sector (manufacturing), and temporality (year of injury). Finally, the amputation cases in this study were matched based on the 11-digit unique personal identification numbers that are designated to Norwegian residents, thus satisfying the final assumption (i.e., correct identification of cases).

A methodical concern about misclassification of injuries is legitimate. We were unable to verify whether either the ANPIC or RWI had misclassified some upper-extremity amputations as another type of injury (e.g., laceration, crush) because of Institutional Review Board constraints. That is, we only had access to cases specifically coded as upper-extremity amputations, but clerical error may have led to some amputations being coded as lacerations or cuts. Identifying misclassified cases would require a review of hospital-based records or another tertiary source of information, such as disability rating. In a study of work-related amputations in Minnesota, Boyle co-workers reported that cases first notified as lacerations and cuts were later confirmed to be amputations after a review of permanent disability ratings reported by the physician to the Minnesota Department of Labor (97). The data utilized in our study were primarily collected for administrative purposes and reported either by the employer or worker. We did not have access to medical data to aid in the verification of the true nature of injuries as suggested by Boyle et al. (i.e., potential misclassifications). The issue of misclassification reinforces the utility of health sector data for injury surveillance in Norway (118). However, the possible misclassification of cases would unlikely alter the conclusions of this study.

Chapman and Chao estimators for the two-source capture-recapture method

The inference about the conservative nature of our Chapman estimates because of positive dependence is supported by the Chao estimates that we computed, but this is not a part of Paper IV. In 1989, Anne Chao proposed an improvement in the estimation of cases that utilizes the two-source capture-recapture method as applied in the estimation of animal populations (i.e., mud turtles) (192). The Chao estimate supposedly provides more reliable results than Chapman's estimator because it has a generally lower relative bias, despite Chapman's lower relative variance (173).

The Chapman estimate assumes that the two sources used for the analysis are independent. This assumption is in fact seldom met by studies that apply the two-source capture-recapture method (173, 188, 189). Our study acknowledges the likelihood of a violation of the assumption of independence (i.e., positive dependence). The Chapman estimate remains the conventional estimator for two-source capture-recapture studies in epidemiology (182, 193-195) and therefore was used in paper IV. The Chao estimate is plausibly pertinent when it is likely that the assumption of independence has been violated.

An increasing propensity to apply the Chaos estimate for the two-source capture-recapture method has been observed in epidemiological studies (196, 197), and an alternative application of this method deserves inclusion in this thesis.

$N_{chao} = n + \alpha_1^{\,2} / 4m$
$n = c_1 + c_2 + m$
$\alpha_1 = c_1 + c_2$
c_1 = number of cases captured in NLIAs registry
c_2 = number of cases captured in ANPIC registry
m = number of cases captured in both c_1 and c_2
N_{chao} = Estimate of total number of cases
Variance = $\alpha_1^{\,2} / 4m * (\alpha_1 / 2m + 1)^2$
95% CI = $N_{chao} \pm 1.96\sqrt{\text{Variance}}$

Table 2. Estimates for upper-extremity amputations in Norwegian manufacturing industry based on Chapman and Chao estimates along with 95% confidence intervals (CI).

Year	$N_{Chapman}$ (95% CI)	N_{Chao} (95 % CI)
1998	183 (137-229)	231(160-302)
1999	104 (82-126)	144 (99-189)
2000	101 (86-116)	148 (106-187)
2001	99 (80-118)	160 (104-216)
2002	121 (87-155)	196 (113-279)
2003	96 (72-120)	132 (85-179)
2004	75 (42-108)	120 (53-187)
2005	85 (41-129)	120 (37-203)
2006	71 (54-88)	105 (63-147)
2007	57 (44-70)	97 (53-141)

Based on the estimates displayed in Table 2, it is possible to infer with some certainty that the total number of cases may lie somewhere between the overlapping confidence intervals of the Chapman and Chao estimates. For example, in 1998, the Chapman estimate yielded 183 cases (95% CI = 137-229), whereas the Chao estimate yielded 231 cases (95% CI = 160-302). The total number of cases for 1998 is likely to be somewhere between 160 and 229. The overlap between the higher bound confidence intervals of the Chapman estimate and the lower bound of the Chao estimate is not restricted to 1998 and can be observed for all of the years (1998-2007). This indicates that the higher bound of the Chapman estimate will most likely include the total number of cases.

Figure 2. Upper-extremity amputation cases reported annually to NLIA RWI and ANPIC, together with respective Chapman and Chao estimates (1998-2007).

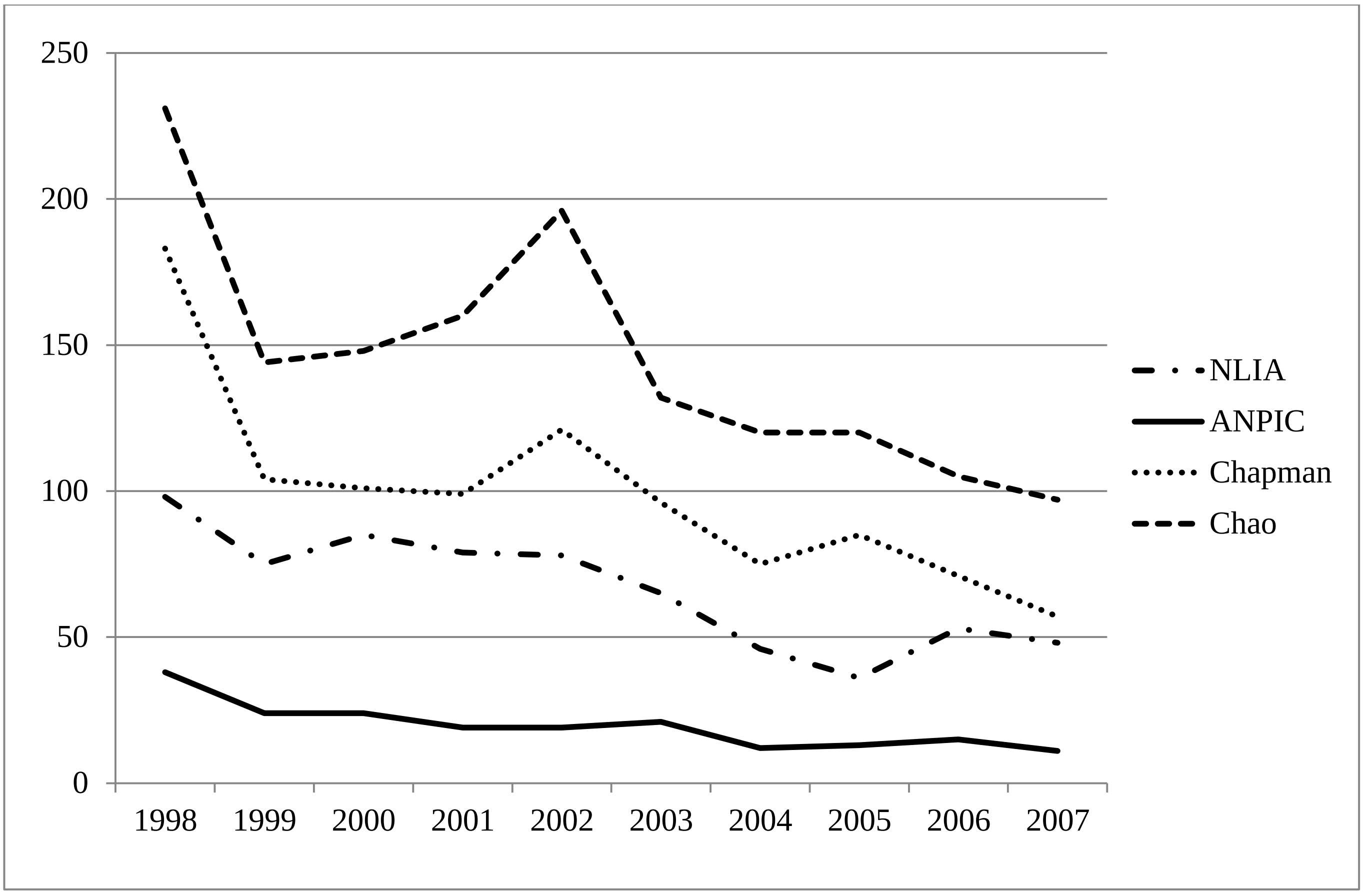


Figure 2 above provides a graphical representation of the tabulated data in the Table 2 above along with the number of cases reported annually to NLIA and ANPIC. The figure illustrates that upper-extremity amputations are underreported across all the years. Importantly, the curves for Chao and Chapman estimates do not necessarily follow the NLIA or ANPIC curves which indicate the number of cases reported. This is because both the estimation methods account for the annual overlap of cases for each year between the two registries utilized in this study. In other words, the low overlap of cases between the two registries (NLIA and ANPIC) indicates a large total population compared to captured numbers; on the contrary, a high degree of overlap indicates that the two registries contain a large proportion of the total population of cases, and the number of un-captured cases are few.

9. CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

9.1 Conclusions

We were able to demonstrate improvements in machine safety as the result of interventions targeted at management that were similar to those achieved through interventions that target safety committees. Validated checklists facilitated the improvement in machine safety among the businesses. We conclude that poorer performing businesses and those that added safety committees were the most likely to improve in terms of machine safety and effectively reduce their risk of traumatic injuries, such as amputations.

In Norway, workers who were male and employed in small businesses within the manufacturing sector were found to be particularly vulnerable to upper-extremity amputations. Wood working, metal fabrication, and meat production were found to be particularly high-hazard workplaces for amputations.

The RWI undercounts the number of upper-extremity amputations, calling for improvements to the injury surveillance infrastructure. The decline in number of upper-extremity amputations in Norway could be partly attributed to improved machine safety. However the recent decline in the number of cases should be seen in context of underreporting and weaknesses in the surveillance infrastructure for traumatic injuries at work.

The data from this study indicates that machines in manufacturing and other high risk industries continue to be a source of hazardous exposure that leads to amputations and other traumatic injuries. The absence of machine guarding and related safety programs remains a serious on-going problem.

9.2 Implications and recommendations

9.2.1 Research

a. Future research should look at the inclusion of both outcome (injuries) and exposure (machine hazards, environmental factors) data attributed to hazardous machines. This will help link hazardous machines to traumatic amputations and provide valuable information to devise preventive strategies.
b. More research is required on the development and application of effective injury prevention interventions for small businesses.
c. Given the ethical dilemmas in the application of a randomized controlled design in occupational health settings, observational studies should be explored as alternatives when evaluating the effectiveness of occupational health interventions.
d. The type of randomized intervention study implemented in Minnesota is relevant for high-risk industries in Norway, given the magnitude of amputations documented in this study. Such a study would also be beneficial in emerging economies, such as China and India that are the new global hubs for manufacturing and face the challenge of traumatic amputations ascribed to hazardous machines.
e. Capture-recapture studies should be encouraged because such efforts will enhance traumatic work-related injury surveillance systems. Future studies that estimate the number of work-related amputations or other traumatic injuries should include multiple data sources, including hospital data.

9.2.2 Practice

a. The checklists and training programs developed in this study are being utilized by businesses in the manufacturing sector to assess machine-related hazards. Validated checklists should be used to assess hazardous machines and work processes as shown in this study.
b. Academia, social partners, and enforcement agencies should consider collaborations for the development of better preventive interventions and improvement of the surveillance infrastructure to address the challenge of traumatic work-related injuries in general and amputations in particular.
c. Given the magnitude of amputations in Norway, the NLIA should consider a strategic initiative for the prevention of work-related traumatic injuries in general and amputations in particular.
d. Quality control procedures must be enhanced by the NLIA to attain better data quality in the RWI.
e. Investigations of traumatic injuries, including amputations, conducted by the NLIA should consider conscientious collection of both detailed injury data and comprehensive data on the machines that caused the injury. Such data will enhance the surveillance infrastructure and help link the injuries to hazardous machines and provide opportunities for more detailed epidemiological analysis.

9.2.3 Policy

a. The effectiveness of safety committees in reducing machine-related hazards was emphasized in the Minnesota study. Establishing safety committees in small high-risk workplaces ought to be given due consideration (< 50 employees).

b. This study showed that small businesses remain vulnerable to traumatic injuries like amputations. Regulatory authorities should deliberate policy interventions that could enhance the levels of occupational safety and health within small businesses in high-risk sectors.
c. The underreporting of traumatic injuries in general and amputations in particular is a major challenge in Norway. NLIA should consider better enforcement of employer's compliance to injury reporting regulations, which would yield better data.
d. The authorities should consider mandating employer reporting of work-related injuries to their insurance companies. At the same time insurance companies that operate in Norway must be mandated to deliver an annual work-related injury data set to ANPIC.
e. The extent of traumatic injuries, including amputations, in Norway calls for policy and advocacy initiatives to enhance the infrastructure for epidemiological research on work-related injuries.

10. REFERENCES

1. International Labour Organization. Occupational Safety and Health. Geneva, Switzerland: ILO, 2012. http://www.ilo.org/global/standards/subjects-covered- by-international-labour-standards/occupational-safety-and-health/lang--en/index.htm (08.07.2012).

2. Smith GS. Public health approaches to occupational injury prevention: Do they work? Inj Prev 2001; 7 Suppl 1: i3-i10.

3. Lander L, Shah RK, Li Y, Mahalingam-Dhingra A, Smith LM, Sorock G.Healthcare cost usage for hospitalised injuries sustained in industrial settings in the USA. Inj Prev 2012 [Epub ahead of print].

4. Ostlie K, Skjeldal OH, Garfelt B, Magnus P. Adult acquired major upper limb amputation in Norway: prevalence, demographic features and amputation specific features. A population-based survey. Disabil Rehabil 2011; 33: 1636-49.

5. Durusoy R, Davas A, Kayalar M, Bal E, Aksu F, Ada S. What kinds of hand injuries are more likely to result in amputation? An analysis of 6549 hand injuries. J Hand Surg Eur Vol 2011; 36: 383-91.

6. Jin K, Lombardi DA, Courtney TK, Sorock GS, Li M, Pan R, et al. Patterns of work-related traumatic hand injury among hospitalised workers in the People's Republic of China. Inj Prev 2010; 16: 42-9.

7. Department of Employment and Economic Development. Positively Minnesota.Minnesota: Department of Employment and Economic Development, 2010. http://www.positivelyminnesota.com/Business/Locating in Minnesota/Major_Industries_Sectors/Manufacturing.aspx (08.07.2012).

8. Statistics Norway. Employment statistics 1998 -2007. Oslo, Norway: Statistics Norway, 2010. (Norwegian)

9. Department of Labour and Industry. Amputation statistics from Minnesota. St.Paul, Minnesota, USA: Department of Labour and Industry, 2010.

10. Norwegian Labour Inspection Authority. Yrkesskaderegister.[Registry of Work- related injuries: Inspections Database]. Trondheim: Norwegian Labour Inspection Authority, 2007. (Norwegian)

11. Loimer H, Guarnieri M. Accidents and acts of God: a history of the terms. Am J Public Health 1996; 86: 101-7.

12. Language Council of Norway. Norsk ordbok [Norwegian word dictionary]. Oslo: University of Oslo, 2012. (Norwegian)

13. Soanes C, Hawker S. Compact Oxford English dictionary of current English.Oxford: Oxford University Press, 2008.

14. Andersson R, Menckel E. On the prevention of accidents and injuries: a comparative analysis of conceptual frameworks. Accid Anal Prev 1995; 27: 757- 68.

15. Smith W, Hall TD. Smith's English-Latin Dictionary. Illinois, USA: Bolchazy-Carducci Publishers, 1871.

16. Oxford University Press. Oxford Dictionaries Online. Oxford: Oxford University, 2012. http://oxforddictionaries.com/definition/english/accident (1.08.2012).

17. Larsson TJ. Accident information and priorities for injury prevention. Doctoral thesis. Stockholm: KTH, Royal Institute of Technology, 1990.

18. Davis RM, Pless B. BMJ bans "accidents". BMJ 2001; 322: 1320-1.

19. Haddon W, Jr. The changing approach to the epidemiology, prevention, and amelioration of trauma: the transition to approaches etiologically rather than descriptively based. Am J Public Health N 1968; 58: 1431-8.

20. Reid C, Chan L. Emergency medicine terminology in the United Kingdom—time to follow the trend? Emerg Med J 2001; 18: 79-80.

21. Evans L. Medical accidents: no such thing? BMJ 1993; 307: 1438-9.

22. Andersson R. The role of accident theory in injury prevention—time for the pendulum to swing back. Int J Inj Contr Saf Promot 2012 [Epub ahead of print].

23. Bijur PE. What's in a name? Comments on the use of the terms 'accident' and 'injury'. Inj Prev 1995; 1: 9.

24. Lund J. Epidemiology, Registration and Prevention of Accidental Injuries.Doctoral thesis. Oslo: Institute of Health and Society, University of Oslo, 2004.

25. Society for Danish Language and Literature. Copenhagen: Den dansk literatur selskab, 2012.http://ordnet.dk/ods_en/dictionary1?query=Ulykke&set_language=en (08.08.2012). (Danish)

26. University of Gothenburg. Svenska akademiens ordbok. Gothenburg, 1997. http://g3.spraakdata.gu.se/saob/index.html (08.08.2012). (Swedish)

27. Girasek DC. How members of the public interpret the word accident. Inj Prev 1999; 5: 19-25.

28. Andersson R. The role of accidentology in occupational injury research. Doctoral thesis. Stockholm, Sweden: National Institute of Working Life, Sweden, 1991.

29. Saari J, Karvonen M, Mikheev M. Accident epidemiology. Epidemiology of occupational health. Copenhagen, Denmark: WHO-EU, 1986.

30. Samant Y, Røyset S, Wergeland E. Conference Presentation. Working on Safety Conference 2010. Whats in a name? Occupational Accidents or Occupational injuries. Rorøs: Working on Safety Conference proceedings, 2010. http://www.wos2010.no/assets/presentations/200.pdf (05.06.2012).

31. Doege TC. An injury is no accident. New Engl J Med 1978; 298: 509-10.

32. Langley JD. The need to discontinue the use of the term. Accident Anal Prev 1988; 20: 1-8.

33. Samant Y, Wergeland E. What's in a name? Accidents or injuries? Occup Environ Med 2011; 68: 81.

34. Waller JA. Reflections on a half century of injury control. Am J Public Health 1994; 84: 664-70.

35. Burnham JC. Accident Prone: A History of Technology, Psychology, and Misfits of the Machine Age. Chicago: University of Chicago Press, 2009.

36. Freud S. The Psychopathology of Everyday Life: (1901). London: Hogarth Press, 1962.

37. Swuste P, Gulijk C, Zwaard W. Safety metaphors and theories, a review of the occupational safety literature of the US, UK and The Netherlands, till the first part of the 20th century. Saf Sci. 2010; 48: 1000-18.

38. Farmer E, Chambers EG. A Study of Personal Qualities in Accident Proneness and Proficiency. United Kingdom: H.M. Stationery Office United Kingdom, 1929.

39. Heinrich HW. Industrial accident prevention. New York: McGraw Hill, 1931.

40. Vernon HM. Accidents and their Prevention. London: The Macmillan Company, 1936.

41. Rodgers MD, Blanchard RE. Accident proneness: A research review: DTIC Document. Oklahoma: FAA, 1992

42. Hale A, Hale M. Accidents in perspective. Pol and Prac in Hlth and Saf 2005; 2: 5-12.

43. Mintz A, Blum ML. A re-examination of the accident proneness concept. J Appl Psychol 1949; 33: 195-211.

44. Arbous A, Kerrich J. The phenomenon of accident proneness. Ind Med Sur 1953; 22: 141-8.

45. Wang X, Yang L, Zhang H. Association of type-A behaviour and personality with accident proneness among drivers. Chn J of Pub Health 2012; 03. http://en.cnki.com.cn/Article_en/CJFDTOTAL-ZGGW201203013.htm (26.08.2012).

46. Andrew H. Britain's most 'accident prone man injured again'. London: The Telegraph, 2010. http://www.telegraph.co.uk/news/newstopics/howaboutthat/7579318/Britains-most-accident-prone-man-injured-again.html (02.07.2012).

47. Rani EK, Chaturvedula S. Accident proneness of pilots in Indian Air Force: An empirical analysis through selection criteria. Ind J Aerospace Med 2009; 53: 36- 44.

48. Geller ES. Behaviour-based safety and occupational risk management. Behaviour modification 2005; 29: 539-61.

49. DePasquale JP, Geller ES. Critical success factors for behaviour-based safety: A study of twenty industry-wide applications. J Safety Res 1999; 30: 237-49.

50. Clissold G, Buttigieg DM, De Cieri H. A psychological approach to occupational safety. Asia Pacific Journal of Human Resources 2012; 50: 92-109.

51. Hopkins A. What are we to make of safe behaviour programs? Saf Sci 2006; 44: 583-97.

52. Howe J. A union perspective on behaviour-based safety. Safety Culture and Effective Safety Management. Chicago: National Safety Council, 2000.

53. Lund J, Aarø L. Accident prevention. Presentation of a model placing emphasis on human, structural and cultural factors. Saf Sci 2004; 42: 271-324.

54. Lehtola MM, van der Molen HF, Lappalainen J, Hoonakker PL, Hsiao H, Haslam RA, et al. The effectiveness of interventions for preventing injuries in the construction industry: a systematic review. Am J Prev Med 2008; 35: 77-85.

55. Breslin F, Kyle N, Bigelow P, Irvin E, Morassaei S, MacEachen E, et al. Effectiveness of health and safety in small enterprises: A systematic review of quantitative evaluations of interventions. J Occup Rehabil 2010; 20: m163-79.

56. Parker D, Brosseau L, Samant Y, Xi M, Haugan D. A comparison of the perceptions and beliefs of workers and owners with regard to workplace safety in small metal fabrication businesses. Am J Ind Med 2007; 50: 999-1009.

57. Kjellén U. Simulating the use of a computerized injury and near accident information system in decision making. J Occup Accid 1987; 9: 87-105.

58. Eastman C. Work-accidents and the law. New York: Charities PublicationCommittee, 1910.

59. Engels F, Wischnewetzky FK. The Condition of the Working-class in England in 1844. United Kingdom: Penguin books, 1987. (Original publication in German in 1845)

60. Virchow RC. Report on the typhus epidemic in Upper-Silesia. Am J Public Health 2006; 96: 2102-5. (Reprint)

61. Davies TA. Evolution of concepts in industrial medicine. Br J Ind Med 1966; 23:165-72.

62. Germov J. Second Opinion: An Introduction to Health Sociology: Oxford, United Kingdom: University Press, 2009.

63. Khanzode VV, Maiti J, Ray P. Occupational injury and accident research: A comprehensive review. Saf Sci 2012; 50: 1355-67.

64. Day AJ, Brasher K, Bridger RS. Accident proneness revisited: The role of psychological stress and cognitive failure. Accid Anal Prev 2012 [Epub ahead of print].

65. Khanzode VV, Maiti J, Ray PK, Tewari VK. Injury severity assessment for underground coalmine workers. Appl Ergon 2010; 41: 242-50.

66. Nichols T. The Sociology of Industrial Injury. Oxford: Taylor & Francis, 2005.

67. Harms-Ringdahl L. Safety Analysis: Principles and Practice in Occupational Safety. Oxford: Taylor & Francis, 2001.

68. Kjellén U. The deviation concept in occupational accident control—I: Definition and classification. Accid Anal Prev 1984; 16: 289-306.

69. Carayon P. Human factors of complex sociotechnical systems. Appl Ergon 2006; 37: 525-35.

70. Lereim I. Traffic accidents and their consequences. A study on injured road users treated at the Regional Hospital of Trondheim. Doctoral thesis. Trondheim: University of Trondheim, 1984.

71. Perrow C. Normal Accidents: Living With High-Risk Technologies. New Jersey: Princeton University Press, 1984.

72. Rasmussen J. Risk management in a dynamic society: a modelling problem. Saf Sci 1997; 27: 183-213.

73. Hovden J, Albrechtsen E, Herrera IA. Is there a need for new theories, models and approaches to occupational accident prevention? Crete, Hellas: Working on Safety Conference paper, 2008. http://www.sintef.no/project/Building%20Safety/Publications/WOS-08-Hovden-Albrechtsen-Herrera.pdf (06.06.2012)

74. Runyan CW. Introduction: back to the future—revisiting Haddon's conceptualization of injury epidemiology and prevention. Epidemiol Rev 2003; 25: 60-4.

75. Haddon Jr W. On the escape of tigers: an ecologic note. Am J Public Health N 1970; 60: 2229-34.

76. Mohan D, Kumar A, Patel R, Varghese M. Development of safer fodder-cutter machines: a case study from north India. Saf Sci. 2004; 4: 43-55.

77. Serinken M, Karcioglu O, Sener S. Occupational hand injuries treated at a tertiary care facility in western Turkey. Ind Health 2008; 46: 239-46.

78. Sabitu K, Iliyasu Z, Dauda MM. Awareness of occupational hazards and utilization of safety measures among welders in Kaduna metropolis, northern Nigeria. Ann Afr Med 2009; 8: 46-51.

79. Liang HW, Chen SY, Hsu JH, Chang CW. Work-related upper limb amputations in Taiwan, 1999-2001. Am J Ind Med 2004; 46: 649-55.

80. Anderson NJ, Bonauto DK, Adams D. Work-related amputations in Washington state, 1997-2005. Am J Ind Med 2010; 53: 693-705.

81. Serinken M, Turkcuer I, Dagli B, Karcioglu O, Zencir M, Uyanik E. Work-related injuries in textile industry workers in Turkey. Turk J Tra Em Surg 2012;18: 31-6.

82. Jin K, Lombardi DA, Courtney TK, Sorock GS, Li M, Pan R, et al. A case-crossover study of work-related acute traumatic hand injuries in the People's Republic of China. Scand J Work Environ Health 2012; 38: 163-70.

83. Friedman L, Krupczak C, Brandt-Rauf S, Forst L. Occupational amputations in Illinois 2000-2007: BLS vs. data linkage of trauma registry, hospital discharge, workers compensation databases and OSHA citations. Injury 2012 [Epub ahead of print].

84. Gavrilova N, Harijan A, Schiro S, Hultman CS, Lee C. Patterns of finger amputation and replantation in the setting of a rapidly growing immigrant population. Ann Plast Surg 2010; 64: 534-6.

85. Boyle D, Larson C, Parker D, Pessoa-Brandao L. Medical, personal, and occupational outcomes for work-related amputations in Minnesota. Am J Ind Med 2000; 37: 551-7.

86. Oleske DM, Hahn JJ. Work-related injuries of the hand: data from an occupational injury/illness surveillance system. J Commun Health 1992; 17: 205-19.

87. Rosenman KD, Reilly MJ, Henneberger PK. Estimating the total number of newly-recognized silicosis cases in the United States. Am J Ind Med 2003;44: 141-7.

88. Sorock GS, Smith E, Hall N. An evaluation of New Jersey's hospital discharge database for surveillance of severe occupational injuries. Am J Ind Med 1993; 23: 427-37.

89. Hasle P, Limborg HJ. A review of the literature on preventive occupational health and safety activities in small enterprises. Ind Health 2006; 44: 6-12.

90. Rautiainen RH, Ledolter J, Donham KJ, Ohsfeldt RL, Zwerling C. Risk factors for serious injury in Finnish agriculture. Am J Ind Med 2009; 52: 419-28.

91. Rivara FP, Thompson DC. Systematic reviews of injury-prevention strategies for occupational injuries: an overview. Am J Prev Med 2000; 18 Suppl 1: 1-3.

92. Zwerling C, Daltroy LH, Fine LJ, Johnston JJ, Melius J, Silverstein BA. Design and conduct of occupational injury intervention studies: a review of evaluation strategies. Am J Ind Med 1997; 32: 164-79.

93. Van der Molen HF, Hoonakker PL, Lehtola MM, Hsiao H, Haslam RA, Hale AR,et al. Writing a Cochrane systematic review on preventive interventions to improve safety: the case of the construction industry. Med Lav 2009; 100: 258-67.

94. Glass B. Small enterprises and occupational health and safety. Encyclopaedia of occupational health and safety. 4th ed. Geneva: International Labour Office, 1998.

95. Kogi K. Advances in participatory occupational health aimed at good practices in small enterprises and the informal sector. Ind Health 2006; 44: 31-4.

96. Brown JD. Amputations: a continuing workplace hazard. Washington, DC: US BLS, Department of Labor, 2003.

97. US Bureau of Labour Statistics. Non-fatal occupational injuries and illnesses requiring days away from work, 2010. Washington DC, USA: US BLS, Department of Labor, 2011.

98. Boyle D, Parker D, Larson C, Pessoa-Brandao L. Nature, incidence, and cause of work-related amputations in Minnesota. Am J Ind Med 2000; 37: 542-50.

99. European Commission. Causes and circumstances of accidents at work in the EU.Brussels: European Commission, 2009.

100. Sorock GS, Lombardi DA, Courtney TK, Cotnam JP, Mittleman MA. Epidemiology of occupational acute traumatic hand injuries: a literature review. Saf Sci 2001; 38: 241-56.

101. McCann M. Metal work and metal working industry. Encyclopaedia of Occupational Health and Safety. 4th ed. Geneva: International Labour Office,1998.

102. Larsson TJ. Severe hand injuries among Swedish farmers. J Occ Accid 1990; 12: 295-306.

103. Larsson TJ. Who will use claims data for the prevention of occupational trauma? Saf Sci Mon 2003; 7: 1-10.

104. Kines P, Mikkelsen KL. Effects of firm size on risks and reporting of elevation fall injury in construction trades. J Occup Environ Med 2003; 45: 1074-8.

105. Bylund P, Bjornstig U. Occupational injuries and their long-term consequences among mechanic and construction metal workers. Saf Sci 1998; 28: 49-58.

106. Carlsson A. Hand injuries in Sweden in 1980. J Occup Accid 1984; 6: 147-53.

107. Pedersen BH, Hannerz H, Tüchsen F, Mikkelsen KL, Dyreborg J. Industry and injury related hospital contacts: A follow-up study of injuries among working men in Denmark. J Occup Health 2010; 5: 147-54.

108. Bergenwall B, Aringer L. Hand injury prevention in Swedish workplaces. 1st European hand injury prevention congress. Bursa: Turkish Hand Injury Prevention Society, 2009.

109. Skov O, Jeune B, Lauritsen J, Barfred T. Arbejdsbetingede handskader. En populsjonsbasert beskrivelse av forekomst og henvendelse til skadestue.[Occuational hand injuries: A population.based description of the incidence and referral to casualty department]. Ugeskr Laeger. 1999; 16: 3285-8. (Danish)

110. Samant Y, Parker D, Wergeland E, Westin S. Work-related upper-extremity amputations in Norway. Am J Ind Med 2012; 53: 241-9.

111. Reigstad A, Hetland KR. Allotransplantasjon av hånd. [Allotransplantation of the Hand]. Tidsskr Nor Laegeforen 2003; 123: 946.

112. Ostlie K, Franklin RJ, Skjeldal OH, Skrondal A, Magnus P. Assessing physical function in adult acquired major upper-limb amputees by combining the Disabilities of the Arm, Shoulder and Hand (DASH) Outcome Questionnaire and clinical examination. Arch Phys Med Rehabil 2011; 92: 1636-45.

113. Reigstad A. Ulykker i Arbeidsmiljøet. En klinisk epidemiologisk studie.[Occupational accidents in the working environment: A clinical epidemiological study]. Oslo: Universitetsforlaget, 1978. (Norwegian)

114. Kjestveit K, Tharaldsen J, Holte KA. Young and Strong: What influences injury rates within construction? Safety Science Monitor 2011; 15: 1-15.

115. Lereim I and Sten T. Sykehusdata om arbeidsulykker.[Hospital data on occupational accidents]. SINTEF Report. Trondhiem: SINTEF, 1986.(Norwegian)

116. Lund J, Bjerkedal T, Gravseth H, Vilimas K, Wergeland E. A two-step medically based injury surveillance system—experiences from the Oslo injury register. Acc Anal Prev 2004; 36: 1003-17.

117. Wergeland E, Gjertsen F, Lund J. Arbeidsskadedødsfall blir underrapportert. [Mortality due to occupational injury is underreported]. Tidsskr f Nor Laegeforen 2009; 129: 981-6. (Norwegian)

118. Søvik S, Lysberg K, Røyset S. Arbeidsskader blant unge arbeidstakere i bygge- og anleggsbransjen. [Occupational injuries among young workers in building and construction industry]. Trondheim, Norway: Norwegian Labour Inspection Authority, 2009. (Norwegian)

119. Aas O, Haugen M, Rian P O, Svendsen K, Løvås G, Slåstad S, et al. Skadefri bonde. [Occupational injuries among farmers]. Trondheim, Norway: St. Olavs Hospital, 2012. (Norwegian)

120. Lereim I. Jord- og skogbruksulykker.[Accidents in agriculture and forestry] Trondheim, Norway: Ulykkesforksningsgruppen RiT/NTNU, 1998. (Norwegian)

121. Bull N. Risk factors for occupational injuries. Doctoral thesis. Bergen, Norway: University of Bergen, 2002.

122. Ytterstad B. The Harstad injury prevention study: hospital-based injury recording and community-based intervention. Doctoral thesis. Tromsø: University of Tromsø, Norway, 1995.

123. Antonsson AB, Birgersdotter L, Bornberger-Dankvardt S. Small enterprises in Sweden: Health and safety and the significance of intermediaries in preventive health and safety 2002. Stockholm: National Institute for Working-Life, 2002.

124. Walters D. Health and safety in small enterprises. Oxford: P.I.E.P. Lang, 2001.

125. Quinlan M, Mayhew C, Bohle P. The global expansion of precarious employment, work disorganization, and consequences for occupational health: a review of recent research. Int J Health Serv 2001; 31: 335-414.

126. National Institute for Occupational Safety and Health. Identifying high-risk small business industries: the basis for preventing occupational injury, illness, and fatality. Cincinnati, USA: National Institute of Occupational Safety and Health,1999.

127. Bull N, Riise T, Moen BE. Work-related injuries and occupational health and safety factors in smaller enterprises—a prospective study. Occup Med 2002; 52: 70-4.

128. Samant Y. Er små virksomhetene mer sårebare enn store? [Are small and micro sized businesses more vulnerable than large businesses?]. Kompass rapport. Trondheim: Norwegian Labour Inspection Authority, 2010. (Norwegian)

129. Goldenhar LM, Schulte PA. Intervention research in occupational health and safety. J Occup Med 1994; 36: 763-75.

130. Kristensen TS. Intervention studies in occupational epidemiology. Occup Environ Med 2005; 62: 205-10.

131. Mancini G, Baldasseroni A, Laffi G, Curti S, Mattioli S, Violante FS. Prevention of work related eye injuries: long term assessment of the effectiveness of a multicomponent intervention among metal workers. Occup Environ Med 2005; 62: 830-5.

132. Lipscomb HJ. Effectiveness of interventions to prevent work-related eye injuries. Am J Prev Med. 2000; 18 Suppl 4: 27-32.

133. Reilly B, Paci P, Holl P. Unions, safety committees and workplace injuries. Brit J Ind Relat 1995; 33: 275-88.

134. Yassi A, Ostry AS, Hatter B, De Boer HM. Joint health and safety committee education and the value of bipartite cooperation in the healthcare sector in British Columbia, Canada. Int J Occup Environ Health 2005; 11: 305-12.

135. Lewchuk W, Robb AL, Walters V. The effectiveness of Bill 70 and joint health and safety committees in reducing injuries in the workplace: The case of Ontario. Ontario, Canada: Canadian Public Policy, 1996.

136. Redinger CF, Levine SP. Occupational health and safety management system performance measurement: a universal assessment instrument. Virginia: American Industrial Hygiene Association, 1999.

137. Yassi A, Spiegel J, Buck B, Sykes M, Lockhart K, Stime B. The Effectiveness of Joint Health and Safety Committees: A Systematic Review. British Columbia: Worksafe BC, 2012.

138. Boden LI. Policy evaluation: better living through research. Am J Ind Med 1996 ; 29: 346-52.

139. Sorensen G, Stoddard A, Ockene JK, Hunt MK, Youngstrom R. Worker participation in an integrated health promotion/health protection program: results from the WellWorks project. Health Educ Behav 1996; 23: 191-203.

140. Ford JK, Fisher S. The transfer of safety training in work organizations: a systems perspective to continuous learning. Occ Med 1994; 9: 241-259.

141. Geldart S, Smith CA, Shannon HS, Lohfeld L. Organizational practices and workplace health and safety: A cross-sectional study in manufacturing companies. Saf Sci 2010; 48: 562-9.

142. Burke MJ, Salvador RO, Smith-Crowe K, Chan-Serafin S, Smith A, Sonesh S. The dread factor: How hazards and safety training influence learning and performance. JApp Psychol 2011; 96: 46-70.

143. Azaroff LS, Levenstein C, Wegman DH. Occupational injury and illness surveillance: conceptual filters explain underreporting. Am J Public Health 2002; 92: 1421-9.

144. McCaffrey DP. Work-related amputations by type and prevalence. Monthly Lab Rev 1981; 104: 35-41.

145. Current Intelligence Bulletin 49. Injuries and Amputations resulting from working with mechanical power-presses. Washington DC, USA: National Institute of Occupational Safety and Health, 1987.

146. Largo T, Rosenman K, Nester M, Reily M, Stanbury M. Work-Related Amputations in Michigan. Michigan, USA: Michigan Department of Community Health, 2009.

147. Thomsen C, McClain J, Rosenman K, Davis L et al. Indicators for occupational health surveillance. Atlanta: US Dept. of Health & Human Services, Center for Disease Control and Prevention, 2007.

148. Gravseth HM, Wergeland E, Lund J. Underrapportering av arbeidsskader til Arbeidstilsynet. [Underreporting of occupational injuries to the labour inspection]. Tidsskr Nor Laegeforen 2003; 123: 2057-9. (Norwegian)

149. Ministry of Health. Ulykker i Norge: Nasjonal strategi for Forebygging av ulykker som medfører personskader 2009-2014. [National Strategy for Prevention of Injuries in Norway (2009-2011)]. Ministry of Health and Care Services: Oslo, Norway, 2009. http://www.regjeringen.no/upload/HOD/Vedlegg/Ulykker_i_Norge-hefte.pdf (28.08.2012). (Norwegian)

150. Bulzacchelli MT, Vernick JS, Sorock GS, Webster DW, Lees PSJ. Circumstances of fatal lockout/tagout-related injuries in manufacturing. Am J Ind Med. 2008; 51: 728-34.

151. Willquist P, Törner M. Identifying and analysing hazards in manufacturing industry – a review of selected methods and development of a framework for method applicability. Int J Ind Erg 2003; 32: 165-80.

152. Association of Norwegian Insurance Companies (ANPIC). Yrkesskader 2010. [Occupational injuries reported to the central agency for private insurers]. Oslo: ANPIC; 2010. (Norwegian)

153. Munshi K, Parker D, Samant Y, Brosseau L, Pan W, Xi M. Machine safety evaluation in small metal working facilities: an evaluation of inter-rater reliability in the quantification of machine-related hazards. Am J Ind Med. 2005; 48: 381-8.

154. Brubaker SA. Optimum machine guarding. Occup Health Saf. 1997; 66: 37-40.

155. Ellenbecker MJ. Engineering controls as an intervention to reduce worker exposure. Am J Ind Med 1996; 29: 303-7.

156. Akbar-Khanzadeh F, Brossia C. Utilization of health and safety consulting services of the Ohio Bureau of Workers' Compensation by small businesses. Appl Occup Environ Hyg 2000; 15: 851-4.

157. Gardner D, Carlopio J, Fonteyn PN, Cross JA. Mechanical equipment injuries in small manufacturing businesses. Knowledge, behavioural, and management issues. Int J Occup Saf Ergon 1999; 5: 59-71.

158. Boden LI, Hall JA, Levenstein C, Punnett L. The impact of health and safety committees. A study based on survey, interview, and Occupational Safety and Health Administration data. J Occup Med 1984; 26: 829-34.

159. Eakin JM, Champoux D, Mac Eachen E. Health and safety in small workplaces: refocusing upstream. Can J Public Health 2010; 101 Suppl 1: 29-33.

160. Jones JH. NIOSH control technology and intervention efforts for small businesses. Am J Ind Med 1999; 36 Suppl 1: 93-5.

161. LaMontagne AD, Barbeau E, Youngstrom RA, Lewiton M, Stoddard AM, McLellan D, et al. Assessing and intervening on OSH programmes: effectiveness evaluation of the Wellworks-2 intervention in 15 manufacturing worksites. Occup Environ Med 2004; 6: 651-60.

162. Kogi K. Work improvement and occupational safety and health management systems: common features and research needs. Ind Health 2002; 40: 121- 33.

163. Kogi K. Collaborative field research and training in occupational health and ergonomics. Int J Occup Environ Health 1998; 4: 189-95.

164. Takeyama H, Itani T, Tachi N, Takanishi T, Inoue T, Murata K, et al. A case study on evaluations of improvements implemented by WISE projects in the Philippines. Ind Health 2006; 44: 53-7.

165. Kochan TA, Dyer L, Lipsky DB, Research WUIER. The effectiveness of union-management safety and health committees. Michigan, USA: WE Upjohn Institute for Employment Research, 1977.

166. Samant Y, Parker D, Brosseau L, Pan W, Min X, Haugan D, et al. Organizational characteristics of small metal-fabricating businesses in Minnesota. Int J Occup Environ Health 2007; 13: 160-6.

167. Trade Union Congress. How the unions make a difference to health and safety. Union effect. London: Trade Union Congress, 2011. http://www.tuc.org.uk/workplace/tuc-8382-f0.cfm (08.08.2012)

168. OECD. OECD Stat Extracts: Trade Union Density. Paris: OECD, 2010. http://www.oecd.org/pages/0,3417,en_36734052_36734103_1_1_1_1_1,00.html (06.06.2012).

169. Lipscomb HJ. The importance of observational methods for evaluation of interventions to prevent occupational injuries. Occup Environ Med 2005; 62: 819-20.

170. Lipscomb HJ, Li L, Dement J. Work-related falls among union carpenters in Washington State before and after the Vertical Fall Arrest Standard. Am J Ind Med. 2003; 44: 157-65.

171. Laporte RE. Assessing the human condition: capture-recapture techniques. BMJ 1994; 308: 5-6.

172. Hook EB, Regal RR. The value of capture-recapture methods even for apparent exhaustive surveys. The need for adjustment for source of ascertainment intersection in attempted complete prevalence studies. Am J Epidemiol 1992; 135: 1060-7.

173. Brittain S, Böhning D. Estimators in capture–recapture studies with two sources. Adv Stat Anal 2009; 93: 23-47.

174. Sullivan KM, Dean A, Soe MM. OpenEpi: a web-based epidemiologic and statistical calculator for public health. Public Health Rep 2009; 124: 471-4.

175. Okun A, Lentz TJ, Schulte P, Stayner L. Identifying high-risk small business industries for occupational safety and health interventions. Am J Ind Med 2001;39: 301-11.

176. Champoux D, Brun J-P. Occupational health and safety management in small size enterprises: an overview of the situation and avenues for intervention and research. Saf Sci 2003; 41: 301-18.

177. Lai C, Tsui K, Kam C. Work-related crushing injuries with amputations of digits, hands and forearms. Hong Kong J Emerg Med. 2007; 14: 22-8.

178. Gavrilova N, Harijan A, Schiro S, Hultman CS, Lee C. Patterns of finger amputation and replantation in the setting of a rapidly growing immigrant population. Ann Plast Surg 2010; 64: 534-6.

179. Friedman LS, Forst L. Ethnic disparities in traumatic occupational injury. J Occup Environ Med 2008; 50: 350-8.

180. Wergeland E, Gjertsen F, Lund J. Arbeidsskadedødsfall blir underrapportert. [Mortality due to occupational injury is underreported]. Tidsskr Nor Legeforen 2009; 129: 981-6. (Norwegian)

181. The Norwegian Surveillance System. Faktaboka. [Factbook]. Oslo, Norway: National Institute of Occupational Health, 2006. (Norwegian)

182. Huang WT, Huang WI, Huang YW, Hsu CW, Chuang JH. The reporting completeness of a passive safety surveillance system for pandemic (H1N1) 2009 vaccines: A capture–recapture analysis. Vaccine 2012; 30: 2168-72.

183. Bernillon P, Lievre L, Pillonel J, Laporte A, Costagliola D. Record-linkage between two anonymous databases for a capture-recapture estimation of underreporting of AIDS cases: France 1990-1993. The Clinical Epidemiology Group from Centres d'Information et de Soins de l'Immunodeficience Humaine. Int J Epidemiol 2000; 29: 168-74.

184. Vergne T, Grosbois V, Durand B, Goutard F, Bellet C, Holl D, et al. A capture-recapture analysis in a challenging environment: Assessing the epidemiological situation of foot-and-mouth disease in Cambodia. Prev Vet Med 2012; 105: 235-43.

185. Razzak JA, Luby SP. Estimating deaths and injuries due to road traffic accidents in Karachi, Pakistan, through the capture-recapture method. Int J Epidemiol 1998; 27: 866-70.

186. Sekar CC, Deming WE. On a method of estimating birth and death rates and the extent of registration. J Am Stat Assoc 1949; 4: 101-15.

187. Seber GAF. The estimation of animal abundance and related parameters: Blackburn Press, New Jersey, USA, 2002.

188. Hu G, Baker T, Baker SP. Comparing road traffic mortality rates from police-reported data and death registration data in China. Bull World Health Organ2011; 89: 41-5.

189. Papoz L, Balkau B, Lellouch J. Case counting in epidemiology: limitations of methods based on multiple data sources. Int J Epidemiol. 1996; 25: 474-8.

190. Hook EB, Regal RR. Capture-recapture methods in epidemiology: methods and limitations. Epidemiol Rev 1995; 17: 243-64.

191. Hook EB, Regal RR. Accuracy of alternative approaches to capture-recapture estimates of disease frequency: internal validity analysis of data from five sources. Am J Epidemiol 2000; 152: 771-9.

192. Chao A. Estimating population size for sparse data in capture-recaptureexperiments. Biometrics. 1989: 427-38.

193. Samuel JC, Sankhulani E, Qureshi JS, Baloyi P, Thupi C, Lee CN, et al. Under-reporting of road traffic mortality in developing countries: Application of a capture-recapture statistical model to refine mortality estimates. PloS one 2012; 7: e31091.

194. Dunbar R, Van Hest R, Lawrence K, Verver S, Enarson D, Lombard C, et al. Capture-recapture to estimate completeness of tuberculosis surveillance in two communities in South Africa. Int J Tuberc Lung Dis. 2011;15: 1038-43.

195. Jules A, Grijalva CG, Zhu Y, Talbot KH, Williams JV, Dupont WD, et al. Estimating age-specific influenza-related hospitalization rates during the pandemic (H1N1) 2009 in Davidson Co, TN. Influenza Other Respi Viruses 2012;6: e63-71.

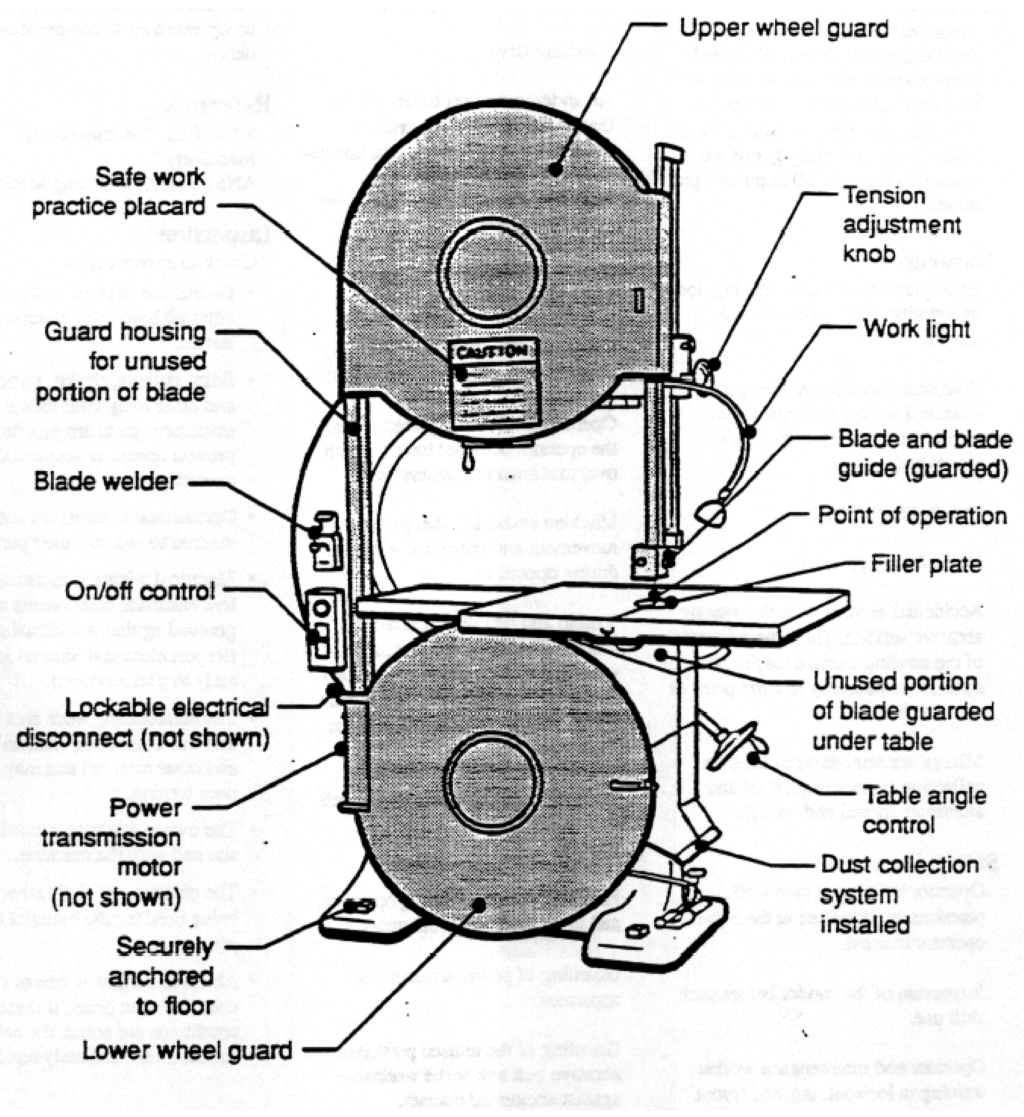
196. Peragallo MS, Urbano F, Lista F, Sarnicola G, Vecchione A. Evaluation of cancer surveillance completeness among the Italian army personnel, by capture-recapture methodology. Cancer Epidemiol 2011; 35: 132-8.

197. Durusoy R, Karababa AO. Completeness of hepatitis, brucellosis, syphilis, measles and HIV/AIDS surveillance in Izmir, Turkey. BMC Public Health 2010; 10: 71.

11. APPENDICES

11.1 Sample machine checklist

BANDSAW



	Yes	No	Priority[a]
Guards for upper and lower saw wheels			**1**
• Present	☐	☐	--1---
• Good condition (no cracks)	☐	☐	--1---
• Yellow color (if metal)	☐	☐	--3---
• Guards are adequate (ie, no hazardous area exposed)	☐	☐	--1---
• Guards have latched access doors	☐	☐	--1---
Enclosure of the saw blade between the upper saw wheel and the saw table			**1**
• Present	☐	☐	---1--
• Has a sliding fixture fastened to the guide that encloses all four sides	☐	☐	---1--
A clear shield that covers the part of the saw blade that runs through the roller guides to the bottom plane of the roller guides	☐	☐	---2--
Power-transmission guard (gears, etc)			**1**
• Guard present	☐	☐	--1---
• Guard yellow in color	☐	☐	--3- -
• Guard in good condition (no cracks, clean, adequate)	☐	☐	--1--
• Band wheels orange in color	☐	☐	--3--
Enclosure of the unused portion of the saw blade, including the portion under the worktable	☐	☐	---1--
Automatic wheel brakes for high-speed vertical friction sawing machines (6,000 to 15,000 f/min)	☐	☐	---2--
Speed index chart	☐	☐	---1--
Operational controls			**1**
• All legibly marked	☐	☐	--1--
• Accessible to operator without having to reach over the rotating/dangerous parts	☐	☐	--1---
• Safeguards that protect operational controls from accidental activation	☐	☐	--1---
• Worktable adjustment wheels yellow in color	☐	☐	--3---

Placards

- Visible and legible safe work-practice placards present ☐ ☐ --3--

Electrical wiring and components 1

- No unguarded live electrical component ☐ ☐ --1---
- No worn or damaged wires ☐ ☐ --1--
- Strain relief present and not loose ☐ ☐ - 2--

Power outage

- Present ☐ ☐ --1--

Lockable disconnect 2

- Present ☐ ☐ - -2--
- In plain view, and within 50 feet of the machine ☐ ☐ - -2-

Emergency stop 1

- Present ☐ ☐ - 1---
- Color coding (Red with yellow background) ☐ ☐ -- 2--
- Readily accessible to the worker ☐ ☐ -- 1--

Owner/Operator manual 3

- On site ☐ ☐ --3--
- Accessible within the work area ☐ ☐ --3-

Job Safety Analysis (JSA) conducted 2

- Lead-worker/ operator's sign-on and sign-off sheet attached to machine ☐ ☐ --2---
- The last entry corresponds with the date and time of the machine's last usage ☐ ☐ --2---

Machine stability

- Adequately stabilized (bolted or anchored to floor/ non-skid mats/ rubber feet/ tar paper/ sufficiently heavy with low center of gravity, i.e., not top-heavy) ☐ ☐ --2---

Surrounding work area 2

- Clean and clear of parts and materials ☐ ☐ --2--
- Non-slip surface ☐ ☐ --2--
- Adequate lighting ☐ ☐ --2--

Labeling of machine 3

- General (model, etc) ☐ ☐ ---3--
- Electrical data plate (e.g., voltage, amperage, RPM, etc) ☐ ☐ -- 3-

11.2 Shop safety checklist

	Environment	Yes	No
1.	Are machines and equipment kept clean and free of trip hazards (good housekeeping)?		
2.	Is there sufficient clearance provided between machines to allow for safe operations, material handling and waste removal?		
3.	Is there adequate lighting in work areas and walkways?		
4.	Are the fire extinguishers at accessible locations?		
5.	Is there no exposed wiring and are all electrical boxes, unused points and knockouts closed with plugs and covers?		
6.	Are extension cords never used instead of permanent wiring (conduits)?		

	Management and Administration	Yes	No
1	Are there records (minutes) of safety committee meetings kept?		

2	Are there records of preventive maintenance on machines?		
3	Is there a written health and safety program that is annually reviewed?		
4	Do you have an AWAIR (A Workplace Accident and Injury Reduction) program?		
5	Does the safety program include machine guarding procedures and policies?		
6	Is there a trained person available on site, to provide first aid on the premises?		
7	Is there a safety bulletin board in addition to the OSHA requirements?		
8	Is the OSHA 300 log maintained?		
9	Are there records of job hazard analyses?		
10	Is there a safety suggestion system for receiving and considering recommendations from employees?		
11	Are MSDS accessible to the employee?		
12	Are there LO/TO procedures posted on each machine?		
13	Are job or machine set up procedures used at the beginning of each new job and work shift?		

	Employees	Yes	No
1.	Are there records of training for all employees in general safety?		
2.	Are there records of employee training in LO/TO procedures?		
3.	Are there records of employee training in machine guarding procedures?		
4.	Are there no observable problems with loose clothing/ jewelry/ long hair?		
5.	Is there adequate PPE? E.g., hearing protection where required; safety glasses worn by all employees in the shop; steel-toed shoes worn by all employees; gloves where required.		
6.	Is there no evidence of bypassing machine guards (like taping down one of the controls on a two-hand control, etc.) or no risk-taking behaviour observed?		

11.3 Marathi summary [4] (मराठी सारांश)

कामगार सुरक्षा: अंगचेद्दना सारख्या (अम्पुटेषन) गंभीर दुखापतींचे प्रतिबंधन

तंत्रद्य्नातील प्रगतीमुळे उत्पादन कारखान्यान मध्ये कामगारांच्या सुरक्षिततेमध्ये जगभर प्रभावी सुधारणा झालेल्या आहेत. तरी देखील अंतरराष्ट्रीय कामगार संघटनेच्या अनुसार प्रतीवर्षी २७० दशलक्ष कामगारांना घातक आणी गंभीर स्वरूपाच्या दुखापती होतातात. रोजगारासाठी कामगार हे यंत्रसामुग्रीचा उपयोग करतात आणी बर्याच दुखापती धोकादायक यत्रांवर्ती घडतात. यंत्रावर कामकरत असताना अवयव अथवा जीव गमावणे तसे दुर्मिळ होत चालले आहे, पण ह्या दुखापतींमुळे कामगारांना होणारे शारीरिक, मानसिक आणी आर्थीक त्रास हे खरे पाहता प्रतीबंधात्मक असतात.

ह्या प्रबंधात मिन्नेसोटा (अमेरिका) आणी नॉर्वे ह्या दोन ठिकाणी केलेल्या कामगार दुखापत प्रतीबंधन संशोधन प्रकल्पातली माहीती सादर केली गेली आहे. ह्या प्रकल्पाचे दोन मुख्यउदेष्य आहेत. प्रथम, कोणत्या प्रकाराचे अंतर्नीरासन किंवा हस्तक्षेप केल्यास यंत्रावर होणाऱ्या अंगाचेद्दना (अम्पुतेषण) सारख्या गंभीर दुखापती प्रतिबंधित होऊ शकतील. दुसरे, कामगारांना होणाऱ्या अंगाचेद्दनासारख्या गंभीर दुखापतींचे कार्यक्षम निरीक्षण करणे, जेणेकरून दुखापत प्रतीबंधक उपाययोजना आखण्यासाठी उत्तम अशी माहीती मिळू शकेल.

ह्या प्रबंधात एकूण चार लेख आहेत. पहिले दोन लेख मिन्नेसोटा बद्दल आहेत, तर पुढील दोन नॉर्वे बाबत माहीती देतात. मिन्नेसोटातील लेख हे प्रामुख्याने कामगारांना होणाऱ्या गंभीर दुखापतींचे प्रतिबंधन प्रभावी रीतीने कसे करावे ह्याबद्दल माहीती देतात. नॉर्वेतील लेख हे उत्पादन कारखान्यांमधील कामगारांना होणाऱ्या अंगाचेद्दना सारख्या गंभीर दुखापतींचे रोगपरिस्थितिविज्ञान (एपीडेमिओलोजी) प्रस्तुत करतात, त्याचप्रमाणे, कामगारांना होणाऱ्या अंगाचेद्दना सारख्या गंभीर दुखापतींचे खरा व्याप किती आहे हे देखील दर्शावितात.

ह्या चार लेखांमधून असे प्रकट होते की यंत्रसामुग्री, विशेषतः उत्पादन क्षेत्रातली यंत्रे हीच प्रामुख्याने अंगछेदन आणी इतर गंभीर स्वरूपाच्या दुखापतींचे कारण असतात. परंतु उत्पादन कारखान्यांमधील सुरक्षा समित्यांचे (५०% मालक आणी ५०% कामगार) अस्तित्व हे कामगारांना होणाऱ्या अंगछेदानासारख्या आणी इतर गंभीर स्वरूपाच्या दुखापतींचे प्रतीबंधनकरण्यास अत्यंत परिणामकारक ठरते. नॉर्वेसारख्या श्रीमंत देशात देखील कामगारांना होणाऱ्या दुखापतींची नोंदणी आणी निरीक्षण यंत्रणा ही दुर्बल आहे. नॉर्वेत कामगारांच्या दुखापातीबाद्दल्च्या माहितीचा दर्जा आणी राशि हे दोन्ही तकलादू आहेत. आता मात्र नॉर्वेत अत्यंत सक्षम आणी दक्ष अशी निरीक्षण योजना उभी करणे हे अत्यावश्यक आहे.

[4] Marathi is the author's mother tongue and is spoken by about 70 million people world-wide, mostly in Maharashtra, India, but also in countries like the USA, UK, Australia and Mauritius, where one finds the Marathi speaking diaspora.

11.4 Other papers from the study in Minnesota

1. Munshi K, Parker D, **Samant Y**, Brosseau L, Pan W, Xi M. Machine safety evaluation in small metal working facilities: An evaluation of inter-rater reliability in the quantification of machine-related hazards. Am J Ind Med. 2005; 48: 381-8.

2. **Samant Y**, Parker D, Brosseau L, Pan W, Xi M, Haugan D, et al. Organizational Characteristics of Small Metal-Fabricating Businessesin Minnesota. Int J Occup Environ Health. 2007; 13: 160-6.

3. Parker D, Brosseau L, **Samant Y**, Xi M, Haugan D. A comparison of the perceptions and beliefs of workers and owners with regard to workplace safety in small metal fabrication businesses. Am J Ind Med. 2007; 50: 999-1009.

4. Brosseau LM, Parker D, **Samant Y**, Pan W. Mapping safety interventions in metalworking shops. Journal of occupational and environmental medicine. 2007; 49: 338-45.

11.5 Papers I-IV

I. **Samant Y**, Parker D, Brosseau L, Wei P. Profile of Machine Guarding in small businesses of Minnesota. <u>American Journal of Industrial Medicine</u>.2006;49: **352-59.**

II. Parker DL, Brosseau LM, **Samant Y** et al. A randomized, controlled intervention of machine guarding and related safetyprograms in small metal-fabrication businesses. Publ Hlth Rep. 2009;124 (1): 90-100

III. **Samant Y**, Parker D, Wergeland E et al. Work Related Amputations in Norway. <u>Am J Ind Med.</u> 2008 Oct-Dec;14(4):272-9.

IV. **Samant Y**, Parker D, Wergeland E Estimating Work-related Amputations in Norway: A 10 year retrospective study using capture recapture method. <u>Int Jou Occ Env Hlth</u> 2012 Oct-Dec;18(4):292-8