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Safe Design and Construction of Machinery

Regulation, Practice and Performance

Elizabeth Bluff

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OF MACHINERY

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ELIZABETH BLUFF
The Australian National University, Canberra, Australia

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About the Author

Elizabeth Bluff has 30 years' experience in occupational health and safety (OHS) and risk management. She is a Director of the National Research Centre for OHS Regulation in the Regulatory Institutions Network, at The Australian National University where she also holds an appointment as a Research Fellow. She has a Bachelor of Science (Hons) from the University of Adelaide, a Masters of Applied Science (OHS) from the University of Ballarat and a PhD in OHS regulation from Griffith University, Queensland.

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List of Abbreviations

ABS	Australian Bureau of Statistics
ANSI	American National Standards Institute.
ASCC	Australian Safety and Compensation Council
ASSE	American Society of Safety Engineers
AWCBC	Association of Workers' Compensation Boards of Canada
BSI	British Standards Institution
CE	Certification Europe
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CSA	Canadian Standards Association
DIISRTE	Department of Industry, Innovation, Science, Research and Tertiary Education (Australia)
DTI	Department of Trade and Industry (UK)
EC	European Community
FEM	Federation of European Materials Handling
HSE	Health and Safety Executive (UK)
HWSA	Heads of Workplace Safety Authorities (Australia)
ILO	International Labour Organization
IRC	Industrial Relations Commission
ISO	International Organization for Standardization
KAN	Kommission Arbeitsschutz und Normung (Germany)
NIOSH	National Institute for Occupational Safety and Health (US)
NOHSC	National Occupational Health and Safety Commission (Australia)
OSHA	Occupational Safety and Health Administration (US)
OHS	Occupational health and safety
PPE	Personal protective equipment
SAA	Standards Association of Australia
SWEA	Swedish Working Environment Authority
UK	United Kingdom
US	United States
VTHC	Victorian Trades Hall Council
WRMC	Workplace Relations Ministers' Council (Australia)

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Preface

This book deals with the inter-related themes of risk, regulation, business practice and performance, based on an in-depth study of safety in the design and construction of machinery. Why machinery – because globally it takes a heavy toll in work-related deaths and injuries. Why design and construction – because removing hazards and integrating control measures at the source is one of the most cost-effective ways to manage risks. This is well recognized in the growing number of public policy and regulatory initiatives addressing health and safety problems 'upstream', including the Australian and European regulatory regimes for machinery safety in focus in this research.

The book is, however, much more than an account of business performance and responses to regulation in a particular context. It takes a fresh look at capacity and motivation as central elements shaping business conduct, and their highly contextualized nature. It offers insights into the impact of state regulation alongside the influence of non-state actors in firms' supply chains and networks.

This means that the book will appeal to an international audience from diverse backgrounds – those interested in human factors and safety engineering, work and product safety, risk management, regulation and socio-legal studies, sociology of work, standard setting and enforcement, and professional or vocational education. And, across these multiple fields, readers may come to the book as researchers, specialists or practitioners, regulators and policy makers, educators or students.

The book itself is multidisciplinary. I hope that by integrating literature and theory from different disciplines with empirical findings about safety in machinery design and construction, the book will help build bridges between specialist, regulatory and practitioner bodies of knowledge and communities of practice. It is my belief that only by applying a multidisciplinary perspective to understanding how and why health and safety problems arise, can we hope to develop and implement effective solutions.

While conducting the research and writing this book I have been working at the National Research Centre for OHS Regulation (NRCOHSR), which is part of the Regulatory Institutions Network (RegNet) at the Australian National University. The manuscript undoubtedly benefitted from discussions with my NRCOHSR and RegNet colleagues, and members of our wider networks. I would like to thank especially four people who read and provided very welcome and constructive feedback on the manuscript at different stages of its development. They are: Professor Richard Johnstone at the Australian Centre for Health Law Research, Queensland University of Technology; Professor Bridget Hutter at the Centre for Analysis of Risk and Regulation, London School of Economics; John Braithwaite, Distinguished Professor and founder of RegNet; and my work health and safety colleague and very good friend Dr Clare Gallagher.

I am also indebted to the 66 manufacturing firms and the 32 staff of the occupational health and safety (OHS) regulators that participated in the research, and gave their time generously to contribute their understandings and experiences of safety in machinery design and construction, regulation and compliance. Finally I would like to thank my partner Des for his continuing encouragement and invaluable insights into the realities of industrial working life, which have also helped to shape my understanding of health and safety, and its implementation in practice.

Elizabeth Bluff
Canberra

Chapter 1
Introduction

What shapes business performance for social goals such as safety? Why are some firms' products inherently safe while others endanger safety? How do state imposed legal obligations and enforcement influence business conduct, and how does their influence compare with that of non-state actors in global markets and supply chains? What role do knowledge and motivational factors play in shaping firms' actions and performance for safety, and how are they constituted? Are specialist bodies of knowledge, such as those for human factors and safety engineering, applied in practice? What are the implications of all of this for safety policy and practice?

These are some of the significant social issues discussed in this book. They are topics that span the interests of researchers, regulators and policy makers, specialists, practitioners, educators and students across multiple fields in safe design, human factors and safety engineering, work and product safety, risk management, regulation and socio-legal studies, sociology of work, standard setting, and professional and vocational education, among others. The book offers readers from these diverse perspectives fresh insights into business responses to public policy, regulatory and professional imperatives, through an in-depth study of risk management in machinery design and construction. The research blends different literatures and theoretical approaches with empirical investigations to enrich understanding of how, to be effective in regulating and managing risks, we need to pay greater attention to the real nature of work and corporate life, and appreciate the complex contextual influences that shape business conduct.

The rationale for examining safety in machinery design and construction stems from the heavy toll that machinery takes globally in work deaths and injuries. Statistical data are not directly comparable between countries but as a broad indication, each year in the European Union machinery is a contributing factor in more than 300,000 injuries, which is 11 per cent of all injuries involving more than three days off work (European Commission, 2008), while machinery is an even more prominent cause of work injuries in China where 30 per cent of injuries treated in hospital emergency departments are machinery-related (Fitzharris, et al., 2011). Annually there are at least 65,000 injuries involving days away from work in the United States (Harris and Current, 2012), 15,000 injuries involving time off work in Canada (AWCBC, 2012), and around 3,500 hospitalizations from machinery-related injuries in Australia (Safe Work Australia, 2009; 2011; 2013a).

From hand-held power tools to complex production systems, machinery may pose genuine and serious risks to health and safety. Most well recognized are mechanical hazards as the following, not uncommon, examples illustrate:

> A machine operator was fatally crushed in a machine. He had entered the service area of a production line to clear an obstruction, triggering an automatic safety device, which stopped the machine. The machine was turned on again by an operator who sat at a console, in a position from which he could not see the operator in the service area.
>
> A farm worker suffered fatal injuries when his jacket caught on the auger of a drilling rig, pulling him into the machine. There was no caging around the drill, interlock or dead-man control on the operating panel. (Examples from NOHSC, 2000, pp. xiii, 86).

As well as the inadequately guarded danger zones and poorly positioned controls that these examples highlight, machinery may be hazardous through weak structures that collapse or break apart, hazardous chemical emissions and leaks, noise and vibration, the ergonomic problems of awkward postures or repetitive movements in machinery operation, and complex human–technology interfaces that give risk to mental strain, human error and hazardous incidents (Al-Tuwaijri, et al., 2008; Backstrom and Döös, 1997; 2000; Brauer 1994; 2006; Gardner, et al., 1999). There is also compelling evidence that a high proportion of machinery-related deaths and injuries are attributable to its poor design and construction in the first instance (Driscoll, et al., 2005; 2008; NIOSH, 2013; Safe Work Australia, 2009, p. 15).

The importance of inherently safe design has been recognized in a series of public policy and professional initiatives in the United States, Europe and Australia, based on the premise that one of the most effective ways to prevent work-related deaths and injuries is to design out hazards and integrate risk control measures at the source (ASSE, 2011; European Commission, 2008, pp. 209–10; Kletz, 1998a; 1998b; Manuele, 1999a; 2008; NOHSC, 2002; Safe Work Australia, 2012a,b; Swuste, 1997; Schulte, et al., 2008). There is also a substantial specialist body of knowledge, originating in the disciplines of human factors and safety engineering, to support the structured analysis and resolution of safety problems from early in the life cycle of machinery (for example Brauer, 1994; 2006; Corlett and Clark; 1995; Green and Jordan, 1999; Karwowski, 2005; Karwowski and Marras, 1999; Morris, Wilson and Koukoulaki, 2004; Stanton and Young, 1999; Stanton, et al., 2005).

On the legal side, the pre-eminent regulatory regime requiring the safe design and construction of machinery is the law of member states in the European Union giving effect to the *Machinery Directive* (European Commission, 1998a; 2006). Australian occupational health and safety (OHS) law also has a well-developed framework of legal obligations for machinery designers and manufacturers (Bluff, 2004; Johnstone, 1997, pp. 260–3; 2004a, pp. 275–80). In other countries the OHS legal obligations of employers may be the impetus for machinery producers to conform to safety standards, as with the American National Standards Institute

(ANSI) standards for safeguarding machinery (Harris and Current, 2014; OSHA, 2014).

The empirical research presented in this book was conducted with Australian firms that manufactured and supplied a wide variety of machinery into international markets, as well as locally. By virtue of the transnational application of the policy, professional and regulatory imperatives outlined above, and the international scope of the literature underpinning them, this research has relevance for an international readership grappling with issues of safety in the design and construction of products, and business responses to policy and regulatory interventions more generally.

In illuminating the mechanisms underlying manufacturers' responses for machinery safety the research also makes wider conceptual and theoretical contributions. It provides insights into knowledge and motivational factors as principal elements shaping firm performance for social and regulatory goals, and advances understanding of how these elements are constituted in the everyday operations of firms and their interactions with external actors.

Overview of the Research

The research presented in this book focused on the design and construction of machinery, as distinct from supply or end use, because in the earlier life cycle stages there is the opportunity to produce machinery that is inherently safer.[1] This can be achieved if those making decisions about design and construction choose structures, materials and components which eliminate hazards, and risk control measures that are integral to the design, compatible with machine functionality, and hence less likely to be removed or disarmed (Kletz 1998a; 1998b; Polet, Vanderhaegen and Amalberti, 2003; Reunanen, 1993, p. 108; Swuste, et al., 1997; Seim and Broberg, 2010).

Centre stage in the research are the European regulatory regime for machinery safety based on the *Machinery Directive* (European Commission, 1998a; 2006), and the obligations of designers and manufacturers in Australian OHS law (Bluff, 2004; Johnstone, 1997, pp. 260–3; 2004a, pp. 275–80). These are leading examples of state regulatory requirements for the safe design and construction of machinery, and the regimes most applicable to the study firms. Although by no means harmonized, the European and Australian regimes contain some common elements. Among these are obligations for the management of risks and provision

1 In later life cycle stages preventive measures are limited to retrofitting risk control measures, avoiding risks arising through poor installation or post-production modifications, and regular servicing and maintenance to help ensure the integrity and efficacy of existing control measures. While these are important preventive measures they do not make machinery inherently safer.

of safety information, and both regimes are underpinned by detailed technical standards[2] for particular types or aspects of machinery.

Taking a wider, de-centred view of regulation the research also examined the non-state actors in local, national and transnational domains that influenced business conduct (see also Black, 2001a; Hutter and Jones, 2007; Parker and Nielsen, 2009). For machinery manufacturers, the state and non-state actors differ according to each firm's operations and markets. They might include state regulators or policy bodies in a firm's home or export countries, national and international standards bodies, business contacts in supply chains or networks (suppliers of component parts, customers or distributors of end products), providers of education and training, professional bodies, industry and trade associations, unions and insurance companies, among others.

The research set a substantive goal of both the Australian and European regulatory regimes for machinery safety as the overarching benchmark of firm performance and compliance. This was the goal of preventing death, injury and illness (the regulatory goal of prevention). For prevention purposes it was critical that manufacturers comprehensively recognized hazards, eliminated those hazards or incorporated risk control measures to minimize the risks, and provided safety information that was accessible to and comprehensively informed end users about machinery safety matters. Keeping the regulatory goal of prevention clearly in focus, the research examined manufacturers' actions and standards of performance for the substantive safety outcomes of hazard recognition, risk control and provision of safety information, and the factors and processes shaping their responses.

The research design and methodology are set out in full in the Appendix. In brief, the sample for the empirical study with machinery manufacturers was drawn from firms in two Australian states (Victoria and South Australia), and included a cross-section of small, medium and large businesses,[3] in capital city and regional locations. Collectively the 66 firms in the sample produced more than 30 different types of machinery or equipment including various types of cranes, hoists and lifting equipment, agricultural and horticultural machinery, boilers and compressors, industrial cleaning systems, and an array of machinery for processing, handling or packaging food, beverages, wood, minerals, vehicles, and other products or waste materials. The study firms supplied their machinery in international markets in Europe, Asia, North America or the Middle East, as well as 15 different industry sectors around Australia. In each study firm, the informants were key individuals responsible for making and implementing decisions about machinery design and construction as directors, owners, or managers overseeing production, engineering and other technical or specialist functions.

2 Technical standards are published documents that establish detailed engineering or technical specifications or procedures; for example, European harmonized standards, Australian Standards and international (ISO) standards (see also Chapter 2).

3 Small = < 20 employees; medium = 20–99 employees; large = 100 or more employees.

A second empirical study with OHS regulators investigated their inspection and enforcement policy and practice for machinery design and construction. Data collection for the two empirical studies involved in-depth, face-to-face interviews in manufacturing firms and with the regulators, supplemented by review of documentation and, for manufacturers, observation of machinery to identify potential sources of harm and risk control measures incorporated or absent. The two empirical studies were underpinned by a legal review and analysis of the principal legal obligations (Australian and European), applying to the safe design and construction of machinery.

The research provided evidence of the mixed performance of manufacturers for hazard recognition, risk control and safety information. More importantly, the research contributed to understanding why some firms performed well for these safety outcomes while others failed to do so. It distinguished knowledge about machinery safety matters and motivational factors (motivations, values and attitudes) as the principal elements shaping firm action and, in turn, performance for substantive safety outcomes. The research also demonstrated the highly contextualized nature of knowledge about machinery safety matters and of motivational factors, as they were constituted in the operations of firms and through interactions with external actors. These external actors might help build capacity or spread misinformation, and they might motivate or constrain preventive action by manufacturers. Key decision makers in firms also shaped firm behaviour through the influence of their personal histories, values and attitudes. State regulation (Australian and European) contributed to the knowledge and motivation to address machinery safety in some firms but, even when state regulation had some influence it had to compete with other constituents of knowledge and motivations. As a consequence, firm behaviour was idiosyncratic and performance for substantive outcomes was often insufficient for firms to comply with the regulatory goal of prevention.

Research Contributions

The research builds on the growing body of scholarship demonstrating the influence of the social and economic contexts of firms' operations on their compliance with state regulation, and performance for safety specifically. Examples of such scholarship are studies of business responses to safety-related legal obligations and enforcement (Fairman and Yapp, 2005a; 2005b; Genn, 1993; Gray and Scholz, 1993; Haines, 1997; Hutter, 2001; 2011; Kagan and Scholz, 1984; Mendeloff and Gray, 2005), and studies of business responses to social and economic regulation more generally (Braithwaite V, 2009; Braithwaite V, et al., 1994; Gunningham, Kagan and Thornton, 2003; Gunningham, Thornton and Kagan, 2005; May and Wood, 2003; Parker, 2002; and see generally Parker and Nielsen, 2011, and contributors therein).

The rich data generated for machinery manufacturers enabled a nuanced account of the principal elements shaping their performance for substantive safety outcomes. These elements are motivations, values and attitudes (motivational factors); knowledge about machinery safety; state regulation (Australian and European legal instruments and enforcement systems); and non-state institutions and actors in the form of technical standards bodies, parties in firms' supply chains and networks, and health and safety professionals. In turn this enabled the development of explanation and theory about the nature of and interplay between these elements and substantive safety outcomes, through inductive reasoning grounded in the empirical data, and deductive reasoning drawing on the literature to interpret the data and interrogate emerging explanation (Marshall and Rossman, 2006, pp. 161–2; Morse and Richards 2002, pp. 169–70; Neuman, 1997, pp. 46–8; Richards, 2005, pp. 128–34; Silverman, 2001, pp. 237–40).

At one level the empirical findings and theorizing from this research converge with and reinforce Parker and Nielsen's (2011, pp. 5, 9–26) conclusion that to explain business behaviour we must understand the influence of and interplay between the goals or priorities that motivate that behaviour, organizational capacities and characteristics that shape decision making and implementation, state regulation and enforcement, and non-state influences. At a deeper level the research makes conceptual and theoretical contributions to understanding and explaining motivational factors and knowledge, their constitution in the everyday operations of firms and interactions with external actors, and how these factors and processes shape firm behaviour and whether or not they comply with state regulation. In essence the research uncovers the web of influences that create plural responses among manufacturers and differentiate their performance for substantive safety outcomes.

The principal motivational factors for machinery manufacturers could be characterized, in a general way, as legal, economic or normative, but not social (see also Ayres and Braithwaite, 1992, pp. 23–5; Kagan, Gunningham and Thornton, 2011; May, 2004; Parker and Nielsen, 2011, pp. 10–12). It was, however, more useful to describe them precisely so as to reveal and make clear their origins and how they influenced firm behaviour. By exploring the mix of influential motivations, values and attitudes it also became clear that, within a particular firm, these factors might be mutually reinforcing or conflicting. Apparent drivers for firms to take action on machinery safety could be cancelled out by barriers to taking such action, as when an espoused moral obligation to protect human health and safety was counteracted by over-riding business concerns about the functionality and marketability of machinery. Moreover, when the relationships between motivational factors and substantive safety outcomes were examined it was evident that only some factors were actually linked with good performance for these outcomes; those that cast machinery safety as in some way integral to the success of the business. Others, for example manufacturers' reputational concerns, were simply espoused motivations, sometimes termed psychological compliance

(Parker and Nielsen, 2009, p. 57), which did not necessarily drive constructive preventive action.

With regard to knowledge, the research established that key individuals (key decision makers) in manufacturing firms constructed knowledge about machinery safety matters from multiple bases but differences in constituents of learning did not, in themselves, explain differences in knowledge about machinery safety. A social constructivist perspective of learning (Billett, 2001; Palincsar, 1998) was useful in theorizing learning about machinery safety in firms, as the research suggested that both social and individual processes were involved in the construction of knowledge about machinery safety. Key individuals constructed safety knowledge principally through participation in everyday activities and interactions with others, within and outside their businesses, and interpreted what they experienced through the lens of their personal domains of knowledge due to their different personal histories, capacities and agency (Billett 1996; 2001; 2003; 2008a; Scribner and Beach, 1993).

State regulation and enforcement were part of the mix of motivational factors and constituents of knowledge in manufacturing firms, although state regulatory demands were generally not well understood and were rather lost among other inputs with which they competed for authority. Intriguingly, specialist human factors and safety engineering sources, which offer information, methods and tools to support the integration of safety in design, were little used in study firms, and only in firms that employed or engaged human factors or other safety professionals. In contrast the influence of the wider external environment of non-state actors was considerable. This influence was represented in firms, and key individuals in firms, privileging parties in supply chains and their industry contacts as drivers of action and sources of information. Yet this research suggests caution in regulators relying on or harnessing such non-state actors to motivate or build the capacity of regulatees, as some safety and socio-legal scholars have proposed (see for example Gunningham and Sinclair, 2002, pp. 17–18; Hopkins and Hogan, 1998; Lamm and Walters, 2004, pp.103–5; Walters, 2001, pp. 52, 375–6; 2002, pp. 45–6). There was little evidence that market and industry influences were linked with manufacturers performing well for substantive safety outcomes and, in some respects, the findings signal the need for regulators to contemplate strategies to reshape or, in worst cases, disarm the counterproductive influence of some market and industry actors.

In essence then, knowledge and motivational factors shaped the quality and rigour of manufacturers' actions for machinery safety and, in turn, their performance for substantive safety outcomes. By their nature, the constituents of knowledge and motivational factors were highly contextualized, complex and unpredictable, as they arose from manufacturers' operations and the mix of practices and interactions in which firms, and key decision makers in firms, participated within and outside their businesses. In some firms, motivational factors, knowledge and actions constituted commitment, capacity and arrangements as the pre-conditions

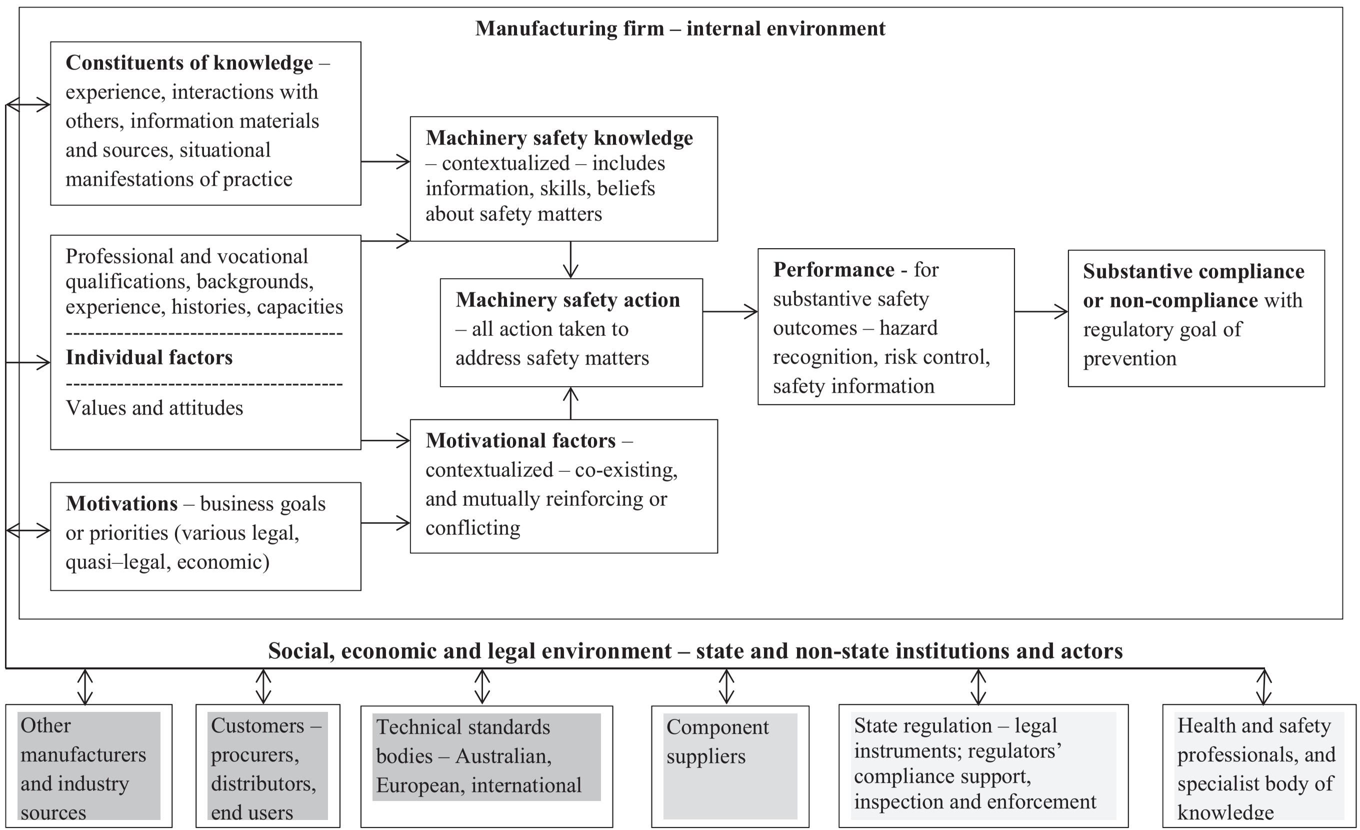

Figure 1.1 The plural constituents of manufacturers' responses for machinery safety

for achieving sound safety performance and complying with the regulatory goal of prevention (on pre-conditions for self-regulation see Johnstone and Jones, 2006; Parker, 2002, p. ix–x, 43–61). In other firms the nature of motivational factors and knowledge impeded or constrained such preventive action.

Two examples illustrate how contextualized knowledge and motivational factors uniquely shaped manufacturers' responses. They show how manufacturers pursuing alternative business goals from different knowledge bases achieved very different standards of performance for substantive safety outcomes.

The first example is a manufacturer of surface finishing machines for use with acrylic, timber, marble, metal and other types of surfaces (Manufacturer 10 in the study). The principal base from which the key individuals in this firm constructed knowledge about machinery safety was their personal experience as end users of surface finishing machines. They had experienced the musculoskeletal strain, vibration, dust and other hazards with this type of machinery. Their knowledge informed the design of a new type of machine. For this firm producing a safe and ergonomically sound machine was a business opportunity, and hence machinery safety was integral to the success of the firm. As the business expanded, the firm's goal of supplying its machine to Europe was the motivation to comply with various European directives relating to machinery safety, which the director had learned about by contacting several business support and government agencies in Australia. In this firm, both knowledge and motivations supported the achievement of substantive safety outcomes. The firm produced an inherently safe machine, applied technology in original ways to address the key hazards, and provided substantial, good quality safety information in a booklet, video and labels on the machine.

The second manufacturer, which produced food processing systems, (Manufacturer 54 in the study) provides a contrasting example. The managing director drew upon his experience as an engineer in the chemical processing industry. He consulted the firm's customers, but not end users of the machinery. He had engaged a consultant to advise on certain aspects of machinery safety but had not sought information about, and had no knowledge of, the firm's legal obligations for machinery safety. The managing director's technical knowledge supported comprehensive hazard recognition and the application of advanced technology to control some risks but his key motivation, the marketability of the machinery, impeded rigorous attention to all safety risks. The firm did not incorporate risk control measures if the managing director perceived that they would reduce the functionality and hence the marketability of the machinery.

An important implication of the empirical findings and theorizing from this research is that as manufacturers made decisions within the framework of their contextualized knowledge and motivations, their decision making was often characterized by bounded rationality (Gigerenzer and Selten, 2001; Simon, 1955). This was evident, for example, in manufacturers' choice to adopt industry standard designs or control measures that were the product of copying other firms' machinery, and were compatible with their own functionality and marketability