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Identifying the human factors associated with the defeating of interlocks on Computer Numerical Control (CNC) machines

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Identifying the human factors associated with the defeating of interlocks on Computer Numerical Control (CNC) machines

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HSL were commissioned by HSE to carry out research which sought to identify reasons why operatives defeat interlocks on Computer Numerical Control (CNC) machines, and to obtain an understanding of the extent of this behaviour across the UK engineering industry. The findings from this research provided a number of valuable insights about the frequency of defeating interlocks and the influences upon this behaviour.

With regard to frequency of defeating, semi-CNC machines were identified as being commonly defeated in the sample* used in this research. Common activities associated with defeating were setting, proving, swarf removal and deburring. Managers, and operatives / supervisors felt defeating was commonplace (the 'norm').

With regard to influences, three sets of influences on operative behaviour (Predisposing, Enabling and Reinforcing) were identified as influencing behaviour in relation to defeating interlocks.

Interventions that take into account these influences could be developed to promote behaviour change. Suggestions for such interventions are provided within this report.

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* It must be noted that these findings are taken from small-scale research and may not generalise to CNC machine users in the UK engineering industry.

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KEY MESSAGES

The current research sought to identify reasons why operatives defeat interlocks on Computer Numerical Control (CNC) machines, and to obtain an understanding of the extent of this behaviour across the UK engineering industry. This research was conducted in two phases. The key messages presented below have been drawn collectively from both Phase 1 (see Annex Report) and Phase 2.

EXTENT OF THE PROBLEM

Current research findings imply that defeating safety devices is widespread within the UK engineering industry, involving a variety of machine types and techniques. However there is a lack of robust evidence in general and specifically in relation to CNC machines. Common activities associated with defeating were setting[1], proving[2], swarf removal[3] and deburring[4]. Semi-CNC machines[5] were identified as being commonly defeated in the sample used in this research. Managers and operatives/supervisors perceived this practice to be the 'norm'. It must be acknowledged however that this finding is drawn from small-scale qualitative research and may not generalise to the larger population of CNC machine users in the UK engineering industry.

FACTORS INFLUENCING OPERATIVE BEHAVIOUR

Characteristics of the individual (e.g. risk perception, knowledge of risks), and the environment (e.g. machine design and procurement), as well as the nature of rewards and/or punishment (e.g. lack of disciplinary action) following defeat of safety interlocks appear to exert an important influence on operatives' behaviours. The current research explored the following three sets of influences upon operative behaviour in the context of defeating interlocks.

- Predisposing: characteristics of the individual that motivate behaviour. Key predisposing factors identified were beliefs about personal susceptibility and negative attitudes about the need for interlocks/guarding.
- Enabling: features of the environment that block or promote uptake of controls. Key enabling factors identified were poor machine design and procurement, lack of refresher/specific interlock use training and confusion regarding legislation/regulations.
- Reinforcing: rewards or punishments that follow as a consequence of behaviour. Key reinforcing factors identified were lack of visible management commitment, production benefits (e.g. ensure the job is run correctly) and lack of consistent enforcement/disciplinary action.

ISSUES FOR CONSIDERATION

Issues for consideration have been drawn from the current research with regard to how to improve health and safety performance and worker involvement (in general and specifically regarding CNC machines/interlocks) within the engineering industry. It is suggested that

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[1] *Setting up a machine to run e.g. selecting the correct programme, ensuring materials are in the right place on the machine. Source: http://en.wikipedia.org/wiki/setting*

[2] *Checking that a programme is running as it should. Source: http://en.wikipedia.org/wiki/proving*

[3] *The removal of swarf (debris e.g. turnings, chips, shavings of meta)l. Source: http://en.wikipedia.org/wiki/swarf*

[4] Removal of burr – (raised edge or small pieces of material remaining attached to a workpiece after machining. Source: *http://en.wikipedia.org/wiki/burr*

[5] *This is not a term recognised in the current EN ISO standard Machine tools – Safety – Turning machines 23125:2010. However it does appear to be used by industry (also known as hybrid machines). It is understood that this term refers to manually controlled machines with limited numerically controlled capability.*

stakeholders[6] should develop pragmatic and cost-effective strategies to help implement such improvements.

[6] *E.g. a collective of machine users, designers, builders, suppliers, employers, employee representatives and regulators.*

EXECUTIVE SUMMARY

BACKGROUND

The defeating of interlocks on Computer Numerical Control (CNC), and other (manual) machines has been identified by HSE (e.g. from COIN[7]/RIDDOR[8] data) as a common problem across small and medium sized engineering enterprises (SMEs). Some anecdotal evidence suggests that despite enforcement action, operatives may continue to defeat interlocks. HSE's experience indicates that the practices often repeat over time within the same organisations. HSE sought a better understanding of operative behaviour regarding the defeating of interlocks to help provide better guidance to inspectors and industry. In turn, this should help improve compliance behaviour and possibly initiate improvements in machinery design and manufacture and machinery procurement by companies.

AIMS AND OBJECTIVES

The Health and Safety Laboratory (HSL) was commissioned by HSE to carry out research to identify the reasons why operatives defeat, or are motivated to defeat/by-pass machinery guarding, particularly the safety interlocks on a variety of CNC machines. A further aim was to determine the extent of the problem associated with the defeating of interlocks on CNC machines.

This report represents the second deliverable (the findings of Phase 2 - interviews and focus groups in a small sample of engineering companies identified as having previously defeated interlocks) of the broader research project. The report from phase 1 (literature review, and secondary data analysis) is provided in the Annex Report. Both phases aimed to give an in depth understanding of the nature and extent of the problem regarding the defeating of interlocks on CNC machines, based on analysis of quantitative and qualitative data.

KEY FINDINGS

Links to Phase 1

The current findings support and expand on the findings from phase 1 (see Annex Report). The findings suggest that characteristics of the individual (e.g. risk perception and knowledge of risks), the environment (e.g. machine design and procurement), as well as the nature of rewards and/or punishment (e.g. lack of disciplinary action following the defeating of safety interlocks) exert an important influence on operatives' behaviours.

Extent of the problem

The current research supports the findings of existing evidence (as described in the Annex Report). It suggests that defeating interlocks on CNC machines is commonplace across the UK engineering industry. This practice was perceived to be the 'norm' within the industry. It must be acknowledged however that this research only collected evidence from a small number of companies and caution should be exercised in generalising this finding to the UK engineering industry. Knowledge of how to defeat interlocks was widespread. Such knowledge was typically acquired from on the job experience operating machines and from peer observation. Interlocks were reportedly defeated on various machine types and brands, particularly on semi-CNC machines using different tools and techniques (the most common tool being an override/dummy key). Key activities associated with defeating included setting, proving, swarf removal and deburring.

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[7] The COIN database holds records of enforcement activity and HSE inspectors' reports on incidents and inspections.
[8] RIDDOR refers to the data obtained from the recording and reporting of accidents and ill health at work by employers. It is a legal requirement under The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995 (RIDDOR).

Factors influencing operative behaviour

Interviews and focus groups identified three sets of factors, which are likely to influence defeat of safety interlocks/guards: Predisposing; Enabling; and Reinforcing. Predisposing factors are individual characteristics that help or hinder the uptake of risk controls. Enabling factors are objective aspects of the environment or system that block or promote the uptake of risk controls. Reinforcing factors are environmental features that reward or punish compliance-related behaviour.

Predisposing factors

Training, experience, as well as witnessing accidents to co-workers emerged as important sources for understanding the risks associated with defeating safety interlocks. Although there was a good understanding of the potentially negative consequences of defeating interlocks, there was a sense that the risks were minimised if operatives were experienced. Risks from defeating safety interlocks were perceived as 'common sense', with experienced operatives perceived to be less at risk compared to their less experienced counterparts. Operating machines at low speeds and standing at a 'safe' distance from the machine were perceived as ways of minimising potential risks. Mixed views were found regarding the effectiveness of risk communication approaches, such as the use of visual signs, to increase awareness of the risks associated with machine operation. It was suggested that this type of risk communication may be effective for apprentices, but less so for experienced operatives as risks were regarded as 'common sense'.

Enabling factors

Interlocks were perceived as necessary for operatives' safety and for general housekeeping. However, the guards supplied as standard on some types of machines were often regarded as unusable and impractical. Machine design (e.g. poor visibility) and task requirements (e.g. manufacturing unusually shaped components) were identified as primary reasons for defeating safety interlocks. Defeating was considered quick and easy to do with a variety of tools/techniques easily accessible to operatives. The safety interlocks on semi-CNC machines were more likely to be defeated due to the perceived lack of flexibility on these machines, and confusion over legislative/regulatory requirements (e.g. whether guards had to be in place at all times or only when operating in CNC mode). This may suggest that operatives lacked understanding of the functionality of machines. Finally, there was little evidence that organisations provided formal, structured forums for involving employees in health and safety.

Reinforcing factors

The majority of organisations had formal disciplinary procedures in place to address incidents associated with defeating safety interlocks. In many cases, defeating was accepted as 'routine' practice for certain types of tasks (e.g. setting and maintenance activities), with disciplinary procedures followed only under certain circumstances (e.g. if defeating took place whilst the machine was running). There was a shared perception that it would not be easy to detect when a safety interlock had been defeated particularly on older machines. Most participants felt that their respective organisations were committed to health and safety in terms of: adequate PPE provision and supervision of apprentices; use of signs reminding operatives about the risks associated with operating machines, and promoting an 'open' culture where operatives felt supported for raising safety concerns. However, management was sometimes perceived as 'turning a blind eye' to the defeating of safety interlocks. It must be noted however that managers did not necessarily acknowledge participating in such acceptance of defeating.

ISSUES FOR CONSIDERATION

The conclusions drawn from the current research are based on the findings from management interviews and operative/supervisor focus groups in UK SME engineering companies. The qualitative data has highlighted issues for consideration regarding improvements to the management and enforcement of operative behaviour:

- All three sets of factors identified (Predisposing, Enabling and Reinforcing) were found to be relevant for understanding operative behaviour, and should be considered in any future intervention to address the defeating of interlocks.

- Poor machine design was identified as a major factor influencing operatives' behaviours. Guards were often considered to be impractical, hampering operatives' ability to do their job. Issues of poor visibility, lack of usability and poor accessibility (to the job and tools) were commonly cited. Guards on some machines were often considered to be there only to protect the machine designers/manufacturers legally, rather than to protect the operatives' health and safety. Identifying and implementing improvements to the design and manufacture of interlocks/guards and machines could prove valuable.

- Potential techniques and devices that could help to reduce the need to defeat interlocks include introducing programme stop[9] and automatic probes[10] when setting. However, the perception was that machines with such functions would be too expensive for most SMEs. Whilst avenues for producing cost effective machines with these or similar functions could be explored, the longer term cost benefits of purchasing machines with such functions could also be highlighted and communicated to industry.

- The current research identified a need for appropriate and pragmatic strategies to help the engineering industry improve health and safety performance both in general and specifically related to the use of CNC machines and interlocks. How to implement such improvements could be explored further.

- Possible interventions are more likely to be effective if the processes required to bring about behaviour change are considered. Contemporary initiatives to standardise behaviour change intervention advocate that eleven broad change processes are factored in to intervention design. Interventions could be developed with these change processes in mind. Specific suggestions are made within this report as to how to do this e.g., raising awareness of personal susceptibility to the risk, recruiting supervisors as health and safety champions, planning and goal setting, refresher training, establishing consistent evaluation and reward systems and improving visible management commitment and worker involvement within the engineering industry.

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[9] *The ability to stop a machining programme mid cycle to open guards and then reinstate guards and restart programme at the same point. http://en.wikipedia.org/wiki/cnc-machinery*

[10] *Devices that eliminate the need for manual tool-setting and job set up. Probes ensure that the tools and work pieces are positioned correctly. Source www.cnc-machine-tool-probe.com*

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1. INTRODUCTION

1.1 RESEARCH OVERVIEW

The Health and Safety Laboratory (HSL) has been commissioned by HSE to carry out research to explore the reasons why operatives defeat interlocks on Computer Numerical Control (CNC) machines.

An interlock is as a switch or other device that prevents activation of a piece of equipment when a protective door is open or some other hazard exists (McGraw–Hill, 2003). Interlocks can be found on many household appliances, e.g. the system by which items such as washing machines cannot be opened whilst they are operating. An interlock may prevent opening by locking the system whilst it is operating, or it may trigger the power to the drive to be cut if a door is opened. There are different levels of interlock and levels of safety they provide. The determining factor in their use is the level of risk and hazard associated with a machine. Box 1 contains some other useful definitions relevant to the context of this work.

- Manual control - mode of operation where each movement of the machine is individually started and controlled by the operator.
- Manually controlled machine - machine for which process steps for the machining are controlled or started by an operator without support by a numerical control (NC) machining program.
- Computer numerical control (CNC) - automatic control of a process performed by a device that uses numerical data while the operation is in progress. It is possible to fit a CNC systems to some previously manually operated machine tools, such as milling machines or lathes. However, this should only be carried out by competent engineers.

Box 1. Useful definitions

1.1.1 Policy background

The defeating of interlocks on CNC and other (manual) machines has been identified by HSE (e.g. from COIN/RIDDOR data) as a common problem in small and medium sized engineering enterprises (SMEs). Current understanding suggests that despite enforcement action, operatives may continue to defeat interlocks. Such behaviour[11] has the potential to result in serious personal injury and fatalities from entanglement and ejection. Tasks that operatives perform when they defeat interlocks include setting/proving, polishing/finishing and swarf removal[12]. Experience indicates that the practices often repeat over time within the same organisations and within similar industries.

1.1.2 Current regulation and guidance

Employers have legal duties regarding machinery and interlocking/guarding devices. The main set of regulations detailing an employer's duty is the Provision and Use of Work

[11] In this context, behaviour refers to an overt visible action or practices that expose an individual to health and safety risks. Behaviour, in turn, is influenced by a range of factors that occur at an individual, social, and organisational level. The terms action and practices are used in this brief to refer to behaviour.

[12] *See Key messages for definitions of these terms*

Equipment Regulations (1998) (PUWER). In accordance with PUWER, (1998) employers and others must ensure that:
- Suitable equipment is provided for the jobs involved;
- Equipment is safeguarded to prevent risks from mechanical and other specific hazards;
- Equipment is provided with appropriate and effective controls;
- Equipment is maintained in good working order and repair;
- Maintenance is carried out safely;
- Information and instruction are adequate;
- Training is provided for operators and supervisors.

There are also requirements under the Supply of Machinery (Safety) Regulations (2008), which affect the manufacturers and suppliers of machinery.

An understanding of the issues relating to type of machines, actual practice and associated incident/accidents is needed for HSE to evaluate the effectiveness of its current approach to regulating the control of risks from the defeating of interlocks. This current research is needed to enable HSE to ensure that its guidance and enforcement approach is directed towards those behaviours and risk control measures which are more likely to result in good practice on the part of duty holders and operatives, and most likely to result in reducing incidents/accidents.

1.2 AIMS AND OBJECTIVES

The overall aim of this research is to identify the reasons, in terms of human factors, why operatives defeat, or are motivated to defeat, machinery guarding, particularly the safety interlocks provided in a variety of CNC machines. Key research questions are:

- What factors influence operatives' decisions and practices in relation to the over-riding / defeat of machinery guarding, particularly the safety interlocks provided to a variety of CNC machines?
- Is it possible to determine the extent of the problem of defeating interlocks on CNC machines?

From answering these research questions a better understanding of operative behaviour when defeating of interlocks will be gained. This will help towards the desired outcome of helping HSE to provide better guidance to its inspectors and industry. In turn, this should help to improve compliance behaviour and possibly improve machinery design and procurement as it is anticipated the research may have implications for how operatives interface with machines and how companies procure machines.

The research consists of two phases, each with specific objectives. Specific objectives for phase 1 are provided in the Annex Report. This report marks the completion of phase 2, the objectives for which are detailed below.

1.2.1 Phase 2 objectives

Phase 2 sought to test the findings from phase 1. It sought to provide an analysis of the context and influencing factors upon operative's behaviour by obtaining the perceptions and opinions of managers, supervisors and operatives within the engineering industry. Specific objectives were:
- To conduct preliminary fact-finding research to inform development of the research tools (face-to-face interview and focus group schedules). This fact-finding research will encompass consultation with subject matter experts (inspectors/specialists) and observation of CNC machines and guards/interlocks.

- To apply the findings from phase 1 (literature review and secondary data analysis) to conduct interviews and focus groups with a carefully selected sample of engineering premises to explore the reasons, in terms of human factors, why operatives defeat or by-pass, or are motivated to defeat or by-pass, the safety interlocks provided on CNC machines.

- To use the results of phases 1 and 2 to identify and provide better guidance and suggestions on techniques available to reduce the perceived need to defeat interlocks, such as programme stop[13] etc.

1.3 ABOUT THIS REPORT

This report summarises the findings from the final phase (phase 2) of this two-year project. The report of phase 1 is contained in the Annex Report. The sections that follow provide an explanation of the research methodology, a summary of the key factors that emerged from the qualitative data collected, and issues to consider that have been identified from the research.

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[13] [13] *The ability to stop a machining programme mid cycle to open guards and then reinstate guards and restart programme at the same point. http://en.wikipedia.org/wiki/cnc-machinery*

2. IMPLICATIONS

The findings of the current research could have several implications for the future management and enforcement of operative behaviour (in the context of defeating interlocks/guards provided to CNC machines). These are considered below.

- The current research identified that the defeating of safety interlocks was perceived as a widespread phenomenon in the UK engineering industry. Three overarching sets of factors were identified as influencing operatives' decisions and behaviours to defeat interlocks. Predisposing factors emerged as important individual characteristics influencing unsafe behaviours and included limited awareness of personal susceptibility to risks, and negative attitudes toward risk communication. Enabling factors also contributed to unsafe working practices and included poor machine design and procurement, and a lack of formal worker consultation on health and safety. Reinforcing factors included a lack of organisational enforcement and disciplinary actions, and beliefs that management either encourage or ignore the overriding of safety interlocks helps to reinforce these unsafe practices.

- An exploration of the influence of these three factors implies that implementing strategies to encourage behaviour change (in the context of operatives defeating interlocks) would be valuable. Defeating interlocks is influenced by factors operating at individual, team and organisational levels. Furthermore, similar patterns and issues emerged in the data gathered from both managers and operatives/supervisors. This implies a need for a holistic approach, incorporating both top-down (e.g. management commitment) and bottom-up (e.g. awareness of personal susceptibility) influences on operative behaviour.

- It is important to consider all possible interventions in terms of the processes required to bring about behaviour change. Behaviour change experts have identified eleven broad change processes (Abraham, 2012) for successful behaviour change. Any intervention should be developed with these change processes in mind e.g. change the physical and social environment, change beliefs and attitudes, reinforce safe behaviours.

- The most prevalent reasons cited for defeating interlocks were poor machine design, impaired visibility, accessibility to tools/job and ease of use. The current research identified many suggestions for improvement. The practicality of these suggestions could be explored e.g. how machine design and procurement could be improved. This could benefit from a collaborative approach as to how to provide CNC machines with reasonably practicable, fit for purpose guards and interlocks. This could be done via workshops for example.

3. METHODOLOGY

3.1 RESEARCH DESIGN

Figure 1 provides an overview of the research design for phase two.

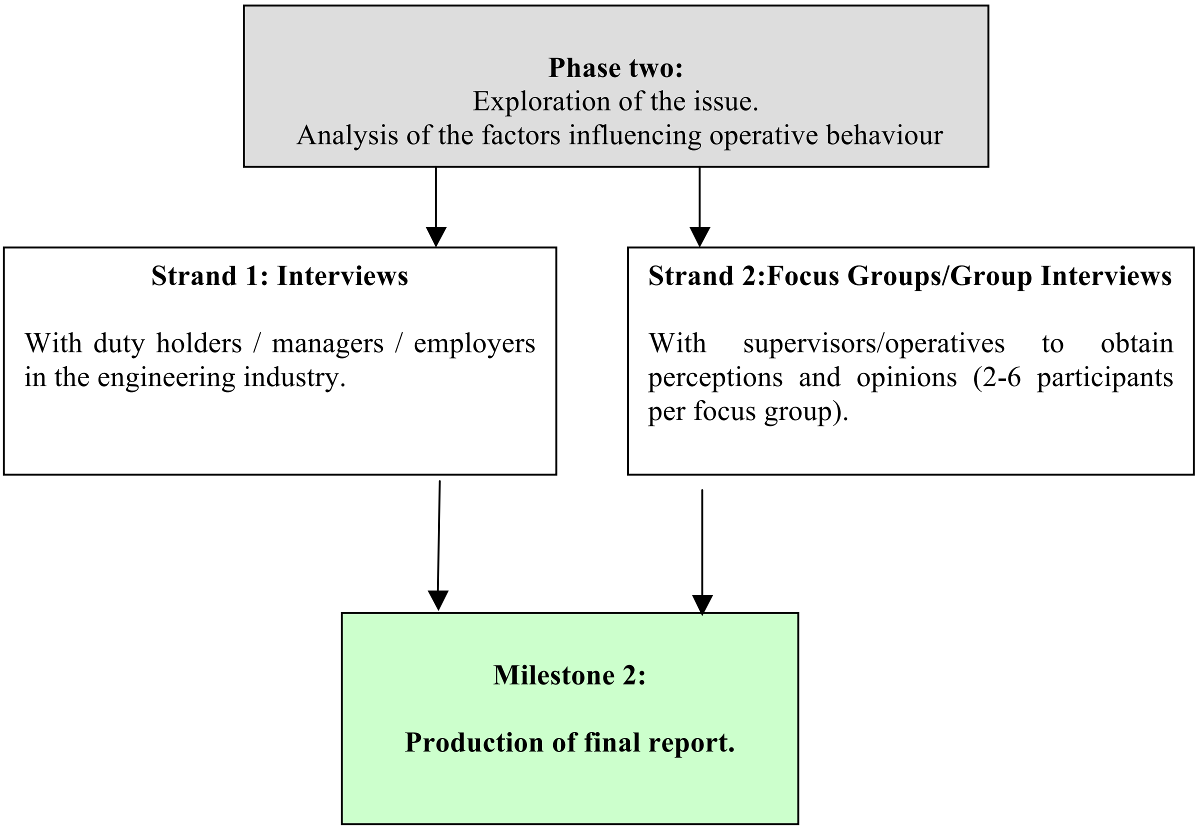

Figure 1: Research design for phase two

The research design for phase two adopted a qualitative approach to add context to the conclusions drawn in phase one using interviews and focus group methodologies. Qualitative methodology allows information to be gathered from the perspective of the interviewee and gives an understanding as to how and why they have that particular perspective. The methodology allows a great deal of in-depth contextual information to be gathered relating to a particular topic. This is particularly important for the first research question where the aim is to understand why operators defeat interlocks on CNC machines.

3.1.1 The interview and focus group questions

Semi-structured sets of interview and focus group/group interview questions were developed by HSL in collaboration with the HSE customer and Social Sciences Unit (SSU). Compiling question schedules in this way with ‘subject matter experts’ (Moser and Kaltman 1979), ensured that the research question(s) were addressed and the appropriate phraseology/terminology employed to ensure participant (and interviewer) understanding (especially for this area where technical jargon is often used). Appendix 1 contains full details of the question set development.

3.2 SAMPLE

Strand 1: Interviews and Strand 2: Focus groups/group interviews

The purposive sample used was drawn from engineering organisations that had previously been served prohibition and/or improvement notices related to the failure to use interlocks/guarding appropriately. Whilst acknowledging the potential skew of such a sample, this strategy was adopted in the anticipation that it would obtain participants that they were known to have defeated interlocks and may have a willingness to divulge practices. HSL researchers used HSE's enforcement and inspection database (COIN) and also obtained the assistance of HSE inspectors to generate a list of suitable organisations that could be invited to participate.

Medium sized and smaller organisations were targeted, rather than large organisations that typically subcontract this type of work to SMEs. Appendix 1 contains detail of the number of organisations contacted and success rate. Views from the all levels of the organisation were sought. Each organisation was invited to participate in management interviews and operative/supervisor focus groups/group interviews in order to obtain a balanced perspective on the issues.

Finally, a one-to-one interview was conducted with a member of HSL's engineering unit. This individual has extensive knowledge and experience within industry of CNC machines (as a supervisor and operative) and had been previously consulted when drafting the question sets. The HSE customer and HSL research team were of the opinion that interviewing this individual would add value and permit further exploration of the research objectives. Appendix 1 contains full details of the sampling strategy employed.

3.2.1 Recruitment

Strand 1: Interviews and Strand 2: Focus groups/group interviews

Once a list of suitable organisations to take part was generated, HSL made initial contact with the organisation via telephone asking for their participation in a duty holder/management interview, and an operative/supervisor focus group/group interview to discuss the key research questions outlined in section 1.2. It was made clear that participation in this research was optional. Full details of the recruitment procedure are detailed in Appendix 1 and Appendix 2.

3.3 PROCEDURE

Strand 1: Interviews and Strand 2: Focus groups/group interviews

The management interview and focus group/group interview were conducted separately on the same day in a private setting (e.g. not an open-plan office) at the participating organisations. The interview with a member of HSL's engineering unit was conducted in a private setting at HSL. The interview schedules for managers and the focus group schedules for operatives followed the same format and covered the same issues. Some slight differences were required when only managers would have the relevant information e.g. the decision process behind machine procurement.

3.3.1 Data collection

Strand 1: Interviews and Strand 2: Focus groups/group interviews

Members of HSL's Human Sciences team collected data via interviews with management and focus groups/group interviews with supervisors/operatives. Due to the size and time constraints of participant organisations a pragmatic approach was adopted and supervisors and operatives were together within the focus groups. The interviews and focus groups followed a semi-structured set of questions (see Appendix 4). Interviews and focus groups were conducted to ascertain participants' perceptions and opinions of the reasons why operatives defeat, or are motivated to defeat, interlocks and guarding devices from an organisational viewpoint. Full details of the data collection procedure can be found in Appendix 1. It should be noted that the number of focus group/group interview participants was dependent on business size and demands and the number of participants willing to participate. Consequently, due to the disparate size of the organisations recruited, focus groups were conducted with between two to six participants.

3.3.2 Data analysis

Strand 1: Interviews and Strand 2: Focus groups/group interviews

Data collected in the semi-structured interviews and focus groups was analysed thematically using the Framework analysis (Ritchie and Lewis, 2003) approach advocated by the National Centre for Social Research (NatCen, Pope et al, 2006). Thematic analysis enabled the researchers to gain an in depth understanding of participants' experiences and practices. A brief overview of the approach adopted by the researchers is detailed below in box 2. Full details of the analysis procedure are detailed in Appendix 5.

- Framework analysis involves a number of stages including identifying the key topics and issues through familiarisation with the interview transcripts and then drawing up an initial analytical (or thematic) framework, into which participants' accounts are systematically summarised and consistently analysed.

- The analytical framework was initially informed by the research objectives, research questions in the topic guides, and by the key issues that were identified from the raw data. The framework was therefore grounded in the data and not imposed by the researchers.

- The summarised data was then worked through in detail, drawing out the elements and dimensions (themes) reflecting the range of experiences and views, identifying similarities and differences, and explaining emergent patterns according to the typologies of Manager/Duty holder and Operative/Supervisor.

- All researchers involved in the data management stage of the analysis provided analytical comments to each interview and focus group/group interview to capture any reflexive comments that were not evident through the transcript. This ensured that those carrying out further analysis had a comprehensive understanding of the interviews and focus groups.

Box 2. Framework analysis approach

4. RESULTS

The following section profiles the responses made by the six engineering companies and one individual who took part in the semi-structured interviews and focus groups/group interviews. Results below are presented collectively from two typologies (groups) (Manager/Duty holder and Operative/Supervisor). Where there are differences of opinion between typologies these are highlighted throughout the results. Where presented, quotes are verbatim and followed by a participant identifier (MAN: Manager/Duty holder participants, OP: Operative/Supervisor participants

4.1 BACKGROUND INFORMATION

4.1.1 Manager/Duty Holders

The final sample for the management interviews consisted of the Managers/Duty holders responsible for health and safety in the organisation. Due to the disparate size and structure of the SMEs that participated (approximately 8-65 employees), there was variety in the roles that participants held. For example, participants' titles/roles included Managing Director, Health and Safety Manager and Manufacturing Manager. In one company, two managers participated in the interview. The sample is detailed in Table 1 below.

Identifier	Job Title	Previous Experience as operative
MAN 1	Quality and Health and Safety Manager	Yes
MAN 2 (2 participants)	General Manager/Director Health and Safety Manager	Yes No
MAN 3	Manufacturing Manager	Yes
MAN 4	Managing Director	Yes
MAN 5	Managing Director	Yes
MAN 6	Health and Safety Manager	No

Table 1. Background information - managers

Daily role/tasks: Participants were asked to provide information about their typical daily role/tasks. Across all participants daily role/tasks included: general management and administrative duties, liaising with clients, work scheduling, and overseeing the health and safety management system (strategies and policies/procedures).

Previous experience: Participants were asked to provide information about their experience prior to becoming managers. As illustrated in Table 1, with the exception of two participants (MAN 2 & 6) all participants had previous experience operating CNC machines. Whilst MAN 6 did not have previous 'hands on' experience, the Managing Director of the company had considerable previous experience as an operative. Therefore the participant held the opinion that there was a good understanding of the practical issues associated with operating CNC machines at management level in this organisation. The same situation arose with MAN 2, the General Manager/Director (also interviewed) had previous experience operating CNC machines.

4.1.2 Operatives/Supervisors

The final sample for the focus groups/group interviews is detailed in Table 2 below. Each focus group/group interview had one supervisor present. Due to the disparate size and structure of the SME's that participated (and their resource requirements on the day) there was variety in the number of operatives available to participate.

OP 7 was an exception. This was an individual who does not currently work within the engineering industry. However, due to their current position in the field of health and safety and their extensive previous industry experience operating CNC machines the research team felt it was justified to gather the experiences, opinions and views of this individual.

Identifier	Number of participants
OP 1	1 Supervisor 2 Operatives
OP 2	1 Supervisor 2 Operatives
OP 3	1 Supervisor 2 Operatives
OP 4	1 Supervisor 3 Operatives
OP 5	1 Supervisor 3 Operatives
OP 6	1 Supervisor 4 Operatives
OP 7	1 Health and Safety Engineer

Table 2. Number of focus group/group interview participants

Daily role/tasks: Participants were asked to provide information about their typical daily role/tasks. Across all participants daily role/tasks included programming, setting and operating CNC machines. Many participants also regularly operated semi-CNC machines and some operated manual machines. In general, participants' roles involved machining and manufacturing components of varying sizes from varying materials (e.g. stainless steel, aluminium, brass, bronze and foam) for clients. Across all participants activities conducted on CNC machines were varied. Common activities included: milling, turning, drilling, and grinding[14].

Length of experience: Participants were asked to provide information about the length of experience they had operating CNC machines. Across all companies participants had

[14] *Milling: The process of grinding materials in a mill. Turning a machining process in which a cutting tool, typically a tool, bit moves linearly while the workpiece rotates. Drilling is a cutting process that uses a drill bit to cut or enlarge a hole of circular cross-section in solid materials. Grinding is an abrasive machining process that uses a grinding wheel as the cutting tool. Source: http://en.wikipedia.org*

extensive previous experience (ranging from 3 – 40 years). OP 6 was the only company in which less experienced operatives participated. In addition to two participants with approximately 25 years each, two participants in the group were currently serving as apprentices.

4.1.3 Types of machines and guards/interlocks

Across the participant companies a variety of CNC machines were used including CNC milling machines, turning machines, lathes and machine centres. A variety of 2,3,4, and 5-axis machines were used[15]. Machines ranged from those that were fully CNC to those that were semi-CNC (i.e. can operate in both CNC and manual modes). In some cases the CNC function was reported as having been fitted retrospectively to a manual machine. Some companies also used manual machines, although manual machine use was generally reported as infrequent. Participants used a variety of different brands of CNC machines including: Cincinnati, Yang, Milton, Mazak, HAAS, XYZ, Jones and Shipman, Colchester, Mori Seki and Harrison.

The types of guards fitted to machines ranged from fully enclosed (side and front) guards on the newer CNC machines to smaller Perspex panels on the front of older and semi-CNC machines. Some machines were reported as having had guards fitted retrospectively. Participants also reported occasionally using magnetic guards in addition to those fitted to the machine. Such guards were regarded as easier to position and were typically used to prevent swarf and coolant ejection.

With regards to the types of interlocks, the mechanisms on the older machines were considered to be more basic e.g. a simple bin and bolt mechanism. Some of the older machines (i.e. pillar drills) had interlocks fitted retrospectively. This was described as a bar that sticks out (like a spring) and if the operative went near the job they would hit the bar first and stop the machine. Interlocks on newer and full CNC machines were reported as typically being some form of electronic sensor on the side and front doors; if either door was opened the sensor went off and the machine stopped operating.

4.2 EXTENT OF THE PROBLEM

Both managers and operatives expressed the opinion that defeating interlocks and removing/overriding guards on CNC machines is a widespread behaviour within industry.

"I can only say that in every other industry every other company I've worked for they've taken the guards off completely." (MAN 3)

"*I'm sure if we were to leave here now and visit three totally separate companies in totally different parts of the country you'd walk in there I would say 85%-90% of the locks would be defeated. That's the reality."* (OP 7)

"*A lot of places I've been those guards have disappeared the second day the machine's been installed and they've never been seen again, they disappear*." (OP 3)

4.2.1 Activities commonly associated with defeating interlocks

[15] *The number of axis relate to the number of ways in which the machine can work a component. Normally machines are three axis, X, Y and Z on a standard coordinate type system. This means the machine can work a component in three planes. The greater the number of axis (the addition of 4th and 5th axis) the more complex tasks the machine can normally carryout. For more information see* *http://wings.buffalo.edu/academic/department/eng/mae/courses/460-564/Course-Notes/CNC%20notes.pdf*

Both managers and operatives expressed similar opinions and experiences regarding the activities that may lead to the defeating of interlocks/overriding of guards. The small sample of qualitative data does not permit a definitive statement regarding which of these activities are most likely to lead to defeating. However, inferences were drawn as to key activities and related issues based on the frequency that these were mentioned/discussed. A more detailed narrative account of the reasons for these activities being associated with defeating is provided in section 4.3.2 (Enabling).

Setting[16]

- A need for visibility when setting jobs e.g. when touching on the tool.
- Setting large or unusual shaped jobs (that cannot fit on the machine with guards in situ).
- Changing jobs and/or tools i.e. a need to set the machine again.
- Setting one piece jobs i.e. not large production batches.
- Setting specialised or expensive jobs that require accuracy and precision.
- Older machines - operatives felt the need to check the process at every step to ensure that machine is doing what it is supposed to (i.e. cutting in the right way).
- To move machine parts - if they have material on the machine operatives need to reference the piece of material to the machine (so the machine knows where it is). On some machines operatives cannot move any part of the machine unless the door is closed, therefore they defeat interlocks to open door and move machine parts.
- Removing guards to set jobs and not replacing when actually running the job – usually to save time.

Operating hybrid / semi CNC machines[17]

- When switching from manual to CNC mode - guards are removed for manual and not replaced during CNC operation.
- When operating in the CNC mode the guards are considered cumbersome and impractical.
- There is confusion about when it is necessary to have locks and guards in place on these types of machines.
- Machines that are retrofitted with CNC – operators claim they could not use machines in programme mode without guards defeated.

Proving[18]

- When an operative has programmed the machine but perceives a need to check the programme is correct and/or see what the machine is doing.

Deburring[19]

- To make sure the job is correct.
- To save time when deburring – for example when the machine is running whilst the operative is at the other end of the material piece de-burring.

Swarf[20] removal

- Accessing the workspace to remove swarf and clear obstructions from machine.

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[16] *Setting up a machine to run e.g. selecting the correct programme, ensuring materials are in the right place on the machine. Source: Source: http://en.wikipedia.org*

[17] Whilst not a term HSE recognises, it does appear to be used by industry (also known as hybrid machines). HSE believe these terms to refer to be manually controlled machines with limited numerically controlled capability.

[18] *Checking that a programme is running as it should. Source: http://en.wikipedia.org/proving*

[19] *Removal of burr – the raised edge or small pieces of material remaining attached to a workpiece after machining. Source: http://en.wikipedia.org/wiki/Burr*

[20] *Swarf is turnings, chips, shavings or filings of metal — the debris or waste resulting from metalworking operations. Source: http://en.wikipedia.org/wiki/Swarf*

Production related issues

- To avoid restarting jobs that take a long time - not defeating the interlock would cause the machine to stop and the programme would have to start again from beginning.
- Piecework - to save time/earn more money.

Maintenance, cleaning and troubleshooting

- Moving the axis of a machine during maintenance and cleaning.
- To access inside the machine when required e.g. to change sensors.
- If the machine fails in some way e.g. the cutting blade in the machine becomes stuck. Operatives unlock the machine to get manual access. It was claimed this would only be to withdraw the blade from the job and would not involve running the machine.

Drilling

- To feel what the machine is doing.
- To access the drill.

Internal work e.g. inside pipes

- When machining inside materials e.g. inside pipes - to see what they are doing.

Removing and replacing collet (described by participant as the sleeve which holds work piece or tool)

- Open the guard to remove collet and have to replace guards when they put the collet in, otherwise the machine will not run.

4.3 FACTORS INFLUENCING OPERATIVE BEHAVIOUR

A variety of influences on operative behaviour were identified in the current research. A wide range of psychological, social, organisational, and environmental factors were found to influence behaviour. Consistent with the approach taken in phase 1 these influences have been categorised according to the PRECEDE model (Green, Kreuter, Deeds & Partridge, 1980) (see Method section in Appendix 1 for full details of this model). This approach helped the researchers structure the findings and identify issues to focus upon.

According to the model, three sets of factors drive behaviour. **Predisposing** factors are characteristics of the individual that facilitate or hinder the uptake of risk controls (e.g. knowledge, risk appraisal). **Enabling** factors refer to objective aspects of the environment/system that block or promote the uptake of risk controls (e.g. skills, visibility of operating field, policy/procedures and training). **Reinforcing** factors are the environmental features of systems that reward or punish compliance related behaviour (e.g. health and safety climate, observable management commitment to health and safety).

This section provides a summary of the key findings identified in terms of the three overarching factors. It should be recognised that in some instances factors overlapped. To aid clarity, influences upon operative behaviour were grouped under one (the most appropriate) factor. Finally, since statistical analysis falls outside the scope of qualitative research, the causal role and strength of influence on operative behaviour for each factor cannot be fully ascertained.

A summary of the key themes is provided below[21].

[21] *N.B as the question sets varied slightly for managers and supervisors/operatives some sub-themes below only discusses data from one typology. Furthermore, for brevity, when discussing responses from operatives/supervisors the text will refer to only operatives (despite including responses from supervisors). Unless specifically pertinent the distinction between operative and supervisor will not be made.*

4.3.1 Predisposing factors

4.3.1.1 Situations perceived as safe to defeat safety interlocks

Managers and operatives were asked whether there were situations where it would be safe to defeat interlocks. Both managers and operatives agreed that defeating safety interlocks was never safe, however there were mixed views regarding whether defeating safety interlocks was a necessity or whether it was a practice that could never be justified.

Some managers and operatives noted that defeating interlocks was a safety hazard and interlocks should always be in place to protect operators from the moving parts of the machine and potential injury.

> *"No they're there for a reason; therefore I can't see that there would ever be reason not to operate them."* (MAN 2)
>
> *"No, it's never safe to defeat it because then you're throwing yourself into an area where you never know what's going to happen if you're overrode it; once you've overrode that key you could lift that door, somebody else could lift that door and then it becomes obviously a safety hazard so there's never a good time."* (OP 5)

On the other hand, some managers and operatives, whilst acknowledging that defeating interlocks was a safety risk, also felt that it was necessary to be able to carry out the job. Specifically, defeating safety interlocks was perceived as necessary for setting activities, where operators needed to be able to see the position of the job, when manufacturing long parts and for accessing machines for cleaning activities (such as the removal of swarf). Reduced visibility when guards were in place was also perceived as a factor contributing to the necessity of defeating safety interlocks.

> *"Part of what we do as a company is produce parts that are very long and we have to take the guards off to do it; if we tend to be doing a part fitting that description it tends to be operated on manually as opposed to under a CNC mode because by its nature alone."* (MAN 3)
>
> *"Setting the data and setting components on with tools, or if you change a tool you know sometimes because of the viewing of coolant and stuff like that, you cannot see it where it's machining and what it's doing, you know, you programme it, you're confident in your programming, what you've done but sometimes, you know, you just need to check"* (OP 1)

Some managers and operatives suggested that defeating interlocks might be done safely if carried out by experienced operatives, if operatives stand at a safe distance from the moving parts of the machines, and if machines are operated at low speeds[22].

> *"I would say so [it is safe to defeat interlocks]...As long as you know what you're doing."* (OP 6)
>
> *"I allow for that with what I do, I have to make sure it is safe, it's all clamped together, sometimes it's experience to hold jobs but you make sure you don't run it anywhere near as quick as somebody, you know...that's running a fully enclosed CNC; you will allow for that."* (OP 4)
>
> *"I mean maybe the doors are open and they're looking in but they're still quite a distance away from the moving and rotating part...I mean their hands aren't touching it."* (MAN 6)

4.3.1.2 Perceived consequences of defeating

All managers and operatives perceived that defeating safety interlocks could potentially have very serious consequences for operatives, including potentially fatal physical injuries. It was acknowledged that coming into contact with the machine while it was running, and exposure to its rotating parts was particularly hazardous. The interlocks' purpose was thus seen as protecting operatives from these risks. A number of risks associated with operating machines without the interlocks activated were cited. These included:

- Clothing or hands getting trapped;
- Facial injuries from the swarf ejected from the machine,
- Tripping and falling towards the machine;
- Cuts;
- Potential injury to co-workers that are in the vicinity of the machine and
- Fatal injuries.

Unlike operatives, managers also mentioned a number of negative consequences for the organisation, which included:

- Prosecution;
- Issuing of fines and notices;
- Potential shut down of the organisation;
- Loss of reputation, and
- Downtime/Loss of productivity associated with incidents as a result of defeating interlocks.

> *"We are aware that there could be a serious accident, entanglement or it could be worse, it could end up in a fatality."* (MAN 6)
>
> *"If somebody was found defeating a safety system, you know, you are liable to prosecution."* (MAN 1)

[22] What operating speeds are permitted by standards varies depending upon the different types of machines being used. For Turning machines refer to "BS EN ISO 23125:2010+A1: 2012 Machine Tools - Safety – Turning". For Machining centres refer to "BS EN 12417:2001 +A2:2009 Machine Tools – Safety – Machining Centres". For Milling machines refer to "BS EN 13128:2001 +A2:2009 Safety of machine tools — Milling machines (including boring machines)".

Some operatives felt that the risks from defeating safety interlocks were 'common sense' and that experienced operatives were less likely to be at risk compared to their less experienced counterparts. There was also a perception that more modern or larger machines posed fewer risks. These were more likely to be fully enclosed thus preventing operatives from accessing them when in operation. Finally, newer machines were perceived as safer because they stopped operating if an interlock was defeated.

"...if you're sensible you don't hold onto anything that's moving." (OP 4)

"The problem comes is when you get an unskilled operator on a machine who hasn't got years of experience, that's where the problems come in. If you've got someone who's an experienced machinist or an operator or a programmer, no problems at all…" (OP 7)

"But the bigger the machine, or certainly the bigger the controls for the machine the more controlled it is, the more it's all enclosed anyhow, in my experience...[…] the bigger machines are so far away from where the operator is that getting in there is virtually impossible …" (OP 3)

Managers and operatives were asked for their views regarding the extent to which CNC machines were more or less risky compared to manual machines. There was a lack of consensus among managers and a diverse range of views was expressed. Some managers viewed CNC machines as posing more risks compared to manual machines, while others felt the contrary was true. On the other hand, there was a greater degree of consensus among operatives. The majority agreed that CNC machines were more dangerous. As different views were expressed between managers and operatives, the respective issues that emerged are discussed separately.

Managers

Those managers who viewed CNC machines as posing greater risks noted that, unlike manual machines, CNC machines were automatic, and thus more difficult to control, and also had more 'moving parts' compared to manual machines. An opposing view was that manual machines are riskier because they have unguarded moving parts and they could cause serious injuries especially if in the 'wrong hands'. On the other hand, CNC machines were viewed as safer when they were operated using the safety interlocks.

"The manual machine someone is controlling it and it's only going by hand and you can stop, but a CNC machine it's being driven by a computer programme, it's moving, it doesn't know somebody's in the way …with the CNC machine if someone was injured or trapped and someone else wasn't around to see that machine would carry on doing damage." (MAN 1)

"I would say manual machines are more risky…By their very nature there are open moving parts; a lathe has a fast spinning chuck which is completely open, you can put your hand on it, you can do anything with it ... you could be working with a drill that's there, this far away from your eyes so safety specs are required where they're not with a fully guarded machine. We advise it but we don't, we don't enforce that they have to wear safety specs." (MAN 4)

"The full CNC's are not a problem you know you can't use them without the guards on" (MAN 3)

"If the CNC machines were used properly with the guards and interlocks on then I would say they are a safe machine." (MAN 6)

One manager noted that machines combining both CNC and manual functions could pose greater risks because they were always operated without the guards.

Operatives

Nearly all operatives viewed CNC machines as riskier because they have the potential of causing more severe injuries compared to manual machines. In addition, because CNC machines were automatic and operated at faster speeds, they were also perceived as 'unpredictable' once a particular program was running. Conversely, manual machines were perceived as safer because they typically operated at slower speeds and their functions could be more easily controlled.

" I mean the manual machines we have here are like the shredder, it's you could hurt yourself but you're maybe talking it's pretty basic injury, you might like get a bruise on your hand, where you try and defeat the CNC, as [name of operative removed] says you could lose your life..." (OP 5)

"Definitely more risk for CNC because like they'll move without warning...Obviously a manual machine, you decide when you move it ..." (OP 7)

"Mainly they'd be manual so there's not a lot of guarding on them…apart from the wheel nothing really is moving at any great speed in a lot of the jobs. It's fairly safe like really." (OP 4)

There was a perception that the risks posed by CNC machines could be mitigated if an operative knows the programme that is being run. On the other hand, the potential for injury is much greater for operators that are unfamiliar with the CNC machine programs.

An alternative view was also expressed; specifically, that manual machines pose greater risks to operators because they are not well guarded compared to CNC machines. However, this was not a widely shared view among the operatives interviewed.

4.3.1.4 Sources of knowledge of risk

Managers and operatives were asked to comment on how they had acquired knowledge regarding the risks associated with the defeating of interlocks. Apprenticeships and previous experience were commonly cited sources of knowledge among both managers and operatives. These sources were also cited as important in understanding the functionality/operating modes of machines, which are discussed in section 4.3.2.4.

Overall, managers felt that they had a good awareness of the risks involved with machines. Several had completed apprenticeships and had previous shop floor experience operating CNC and manual machines before gradually moving up the hierarchy within their respective organisations. Similarly, operatives felt that apprenticeships had provided them with an appreciation of the risks and the importance of always using the safety interlocks when operating machines. Experience in operating machines was also perceived as crucial in understanding the risks. Several of the operatives interviewed had several years of experience working on manual machines and eventually on CNC machines; this breadth of experience enabled them to appreciate the pitfalls of machining. There was a sense that knowledge about the risks becomes 'ingrained' over time as experience of operating machines enables workers to anticipate and recognise what to look out for. Learning on the job from experienced workers was also seen as an important source of knowledge for inexperienced operatives, who were perceived as more vulnerable to risks.

However, a number of operatives felt that experience alone was not sufficient and that it was important to also use ‘common sense’ to help guard against the risks. Operatives provided several ‘real-life’ examples, such as not running in front of a car, to illustrate the importance of using common sense to protect oneself from injury when operating machines.

“…we’re all time served people...especially the older guys, we’ve started off on manual machines and progressed to CNC we know the pitfalls of machining.” (OP 6)

“ […] if you’ve had a proper apprenticeship you tend to respect the machines you’re on and you don’t take the guard, you don’t take the interlocks off, you know you see and you think I’m not taking that off, no way.” (OP 4)

“For engineering training it would obviously revert back to my apprenticeship and my years of experience as a I ran my own engineering business before turning to a limited company…” (MAN 4)

“I mean obviously somebody who’s been on it say a month is obviously not going to have as much safety knowledge of the machine as somebody who’s been on it say for ten years...” (OP 5)

“Yeah, there are a few things you need to pick up on the way as well, not...but again it always comes down to commonsense.” (OP 1)

“You could put your hand in but that’s unlikely to happen they’re all really skilled guys and they’ve been doing it all of their lives so the chances of someone going ‘oh well I'm going to put my hand on the cutter’ is remote.” (MAN 3)

Previous incidents in the organisation and/or notices served as another possible source of knowledge regarding the risks associated with defeating interlocks.

Witnessing accidents happening to co-workers was another source of knowledge of the risks associated with operating both CNC and manual machines. Examples were given where participants had watched co-workers’ sleeves being caught in rotating tools or losing their fingers as a result of being trapped in the machine. Some managers also mentioned that having improvement notices served and their interactions with HSE Inspectors had also enabled them to appreciate the risks involved.

Training received from machine manufacturers on the specific machines purchased was cited as another source of knowledge about the risks associated with operating machines. Further, it was described that operatives would often pick up knowledge from the machine manufacturers when they visited their premises to either install a machine or carry out maintenance. However, the training provided by the machine manufacturers did not appear to involve learning about the importance of using safety interlocks.

Finally, some operatives discussed the use of visual signs on machines as reminders regarding the risks associated with machine operation. These could involve pictures or ‘colourful charts’, as they were described, which were used to highlight the dangers and the types of injuries that could be sustained if machines were not operated safely. There were mixed views regarding the effectiveness of imagery; some operatives suggested that it may be effective especially for apprentices to enable them to appreciate the dangers of operating machines unsafely, whilst others suggested that it would have little impact because the risks are regarded as 'common sense'.

4.3.1.5 Communication of health and safety

Managers and operatives discussed a range of channels that were used to communicate health and safety in general in their respective organisations. The use of written communication and informal discussions with line management appeared to be the most prevalent means of communication about health and safety.

Written communication in general included health and safety manuals, notice boards, memos as well as signage on machines and around the site specifically for machine safety. For instance, examples were given where photos of first aiders were put on the notice board so that everyone knew 'who is who'. In addition, signs, posters as well as videos were also used to communicate health and safety information, such as the dangers of working with machinery and the importance of wearing PPE. However, the general sentiment was that health and safety videos and signs/posters was an ineffective means of risk communication because they tend to be ignored by operatives.

"Anything to do with health and safety is obviously communicated on the notice board. There's a works handbook with health and safety stuff in it." (MAN 4)

"There are actually signs that are sort of bolted onto the machines that came with them from the manufacturers, it tells you all about the electricity of it as well and, as well as what would be expected… that the guarding should be in place." (MAN 6)

"… it's just wall coverings isn't it after you've seen it the first time, do you ever notice it again, sometimes not really." (OP 3)

In some cases, there were formal structures in place for general health and safety communication, such as health and safety meetings, where health and safety issues were discussed and then cascaded to the workforce. Toolbox talks also took place in some organisations. These were organised by the foreman and were used to communicate health and safety messages. However, toolbox talks did not appear to be a common communication channel and in some cases they did not take place at all.

In most cases, however, communications between management and workers on health and safety were predominantly informal. Typically, operatives would raise any safety issues with either the Health and Safety Manager or their supervisor who would then raise it with senior management. Informal conversations between management and operatives were also held during management walk rounds. Some managers reported spending a lot of time on the shop floor, which provided opportunities to speak to operatives on health and safety in general, and for machine safety and to find out personally about potential safety concerns.

"We've tried them [toolbox talks] in the past; we don't tend to do them now...I think nowadays we're done to death with health and safety really, especially in engineering." (MAN 4)

"I don't think there's any regular team talks about it [health and safety]" (OP 3)

"That [toolbox talks] used to happen a few years ago, but that stopped as well didn't it? Well if you've got a safety issue, it's (name of H&S Manager) you go and see, that's about it." (OP 6)

"I'm out in the workshop every day, morning and afternoon, just whatever crops up and I mean the guys do feel free to speak to me or ask me advice on things or whatever and the same with their foreman." (MAN 6)

Lessons learnt from incidents involving machines were sometimes communicated in the form of presentations, prepared and delivered to the workforce by the workers who were involved in the incident. Management was also involved as a means of reinforcing the organisation's health and safety objectives and the responsibilities of both employers and employees for health and safety. For instance, an example was given where two apprentices cut their fingers whilst cleaning a CNC machine. The apprentices were asked to prepare a short presentation on what went wrong and to highlight where they deviated from safe practices.

4.3.2 Enabling factors

4.3.2.1 Opinion of controls

Managers and operatives were asked for their opinions of controls (interlocks and guards). There was consistency of response across both managers and operatives. In terms of adequacy, some respondents were very positive about the controls. Others, acknowledged the need for guards and interlocks, but did not regard them as consistently necessary and viewed them as often '*over the top'*, an inconvenience, impractical and hampering their ability to work. The guards supplied as standard on some types of machines (particularly semi-CNC machines) were regarded as often unusable, making access to, and use of the machine difficult. The opinion was that such guards often have to be removed to operate the machine. Guards that permit accessibility were considered most effective.

The ability to operate machines with guards open without defeating the interlocks was perceived to depend upon the type and age of machine. Guards on older machines were generally considered easier to defeat. Newer machines were described as more user-friendly, e.g. visibility is improved but it was noted that improved guarding means it is frustrating that the doors cannot be opened as easily.

Both managers and operatives suggested that in some cases interlocks and guards are only provided to afford legal protection to manufacturers. In such circumstances the guards and interlocks were considered inappropriate e.g. in order to save money manufacturers put poor quality guards on machines. This was considered to encourage operatives to defeat guards, as the machine is not fit for purpose with them in situ.

The use of probes (both mechanical and automatic) was discussed. Probes are devices that help set the position of the machine on the material being machined. Probes used included laser and mechanical probes. In general probes were considered a good control measure. Probes were regarded as an aid to setting up and positioning jobs. Some of the participant organisations had machines with built in automatic probing systems. These machines were perceived as more effective, allowing setting to take place automatically. The opinion was that there are less visibility issues and therefore interlocks should not need to be defeated (i.e. no need to 'eyeball' the job). It was noted however that automatic probing systems, whilst more effective are expensive.

> *"I think in some sense, in quite a few instances yes they are necessary…but there is instances...when they're impossible to work with… they are physically impossible for us to have on the machine and we have to take the things off."* (OP 3)
>
> "*And the older machines, you can do anything with the door open apart from run the spindles so you can move things, wrap things, bring things down, set things."* (OP 4)
>
> *"I think interlocks are put on so the manufacturer has covered his backside but when they've put them on they might not have fully understood what that machine is doing or what people might be doing on it."*(OP2)

Regarding the purpose of interlocks/guards there was consistency of opinion across managers and operatives. Their purpose was broadly explained in two sub themes. The first of these was safety. Interlocks were perceived as necessary to protect operatives; keep people away from machine moving parts, prevent entanglement of clothing or body parts in the machine and preventing pieces of metal, swarf, broken tools etc being ejected from the machine injuring operatives. Protecting respiratory health was also cited. Housekeeping was the second theme. With regard to housekeeping, guards were considered important to keep the workplace tidy e.g. prevent swarf, metal working fluid, oil and coolant being ejected from the machine onto the surrounding floor and workshop space.

"They're there a) to stop you getting your fingers in places where they shouldn't be...Protection basically...b) stop you getting hit by flying swarf and coolant etc. All the rest of the stuff that comes flying out, broken cutters, drills, anything else that can come flying off that table and strike you or somebody else..." (OP 3)

*"Stop you getting dragged into the machines." (*MAN 6)

"*Also you're breathing in a lot of stuff you don't want to out there, especially if they've got extraction on them as well."* (OP 4)

"And generally keep the place tidier, because if it's been closed it's not going everywhere." (MAN 3)

4.3.2.2 Reasons to defeat interlocks

Both managers and operatives identified a variety of reasons for defeating interlocks and guards. The most prevalent reasons cited related to machine design, specifically visibility, usability, and accessibility issues.

Visibility was considered to be impaired primarily because of dirty/damaged viewing panels on guards. Most companies reported cleaning the viewing panels on guards as required or within a daily/weekly programme. However, even when guards were clean managers acknowledged that operatives wanted to open them to improve visibility as cleaning does not preclude swarf scratching and deteriorating the screens. Related to this point it was suggested that operatives have a curiosity and a perceived need to check that the machine is doing what it is programmed to do e.g. to avoid the need to scrap jobs if the programme is not running as it should. The need to change viewing panels regularly was also recognised, however it was suggested that this did not happen due to cost and the requirement for the machine to be out of operation whilst this happened. In addition to the degradation of viewing panels over time a general lack of light and visible access to the job was discussed. Internal machining (e.g. inside metal pipes) was perceived as a situation that better visibility would not negate the need to defeat interlocks, as operatives want to see inside the component.

It was suggested by one manager that lack of visibility might be used as an excuse to defeat. It was also commented by some managers and operatives that modern machines often have better visibility due to their design thereby eliminating the reasons to defeat. It was emphasised by several managers that defeating interlocks is not accepted whilst the machine is actually running, as operators do not need to have visibility at this stage. Finally, a need to hear what a machine is doing was cited as a reason to defeat.

"The main reason in my experience that we overrode them and we did when I was on the machines, was down to visibility…once that machine has been running for six or seven weeks because of the amount of swarf and debris flying around, the Perspex glasses get very very damaged and the visibility becomes poor."(MAN 1)

"But no, I mean they all have the panels and we've checked them all, clean them on a regular basis and whatever but, oh no, they just want to actually be in there and see it." (MAN 6)

"…it's down to visibility…It's like driving in the dark without your headlights on." (OP 2)

"Double check that what they've just programmed in to happen happened." (MAN 2)

"*But even if it's not in-between the window, it's still...pretty dark...You still can't see inside a bore to touch on a job for setting up tooling…And the machines are quite big, some of them, are quite far away from the window...It'd be impossible to try and accurately set up a job."* (OP 6)

"A lot of the machines is by ear like really…You're gonna hear something go wrong before you see it like…hearing is a big part of engineering." (OP 4)

With regard to usability and accessibility, a need for flexibility (differing requirements depending on the job being done) was highlighted. Several specific examples were given relating to this point e.g. when producing one off components rather than large batches that can be set up and run, (when machining large batches there was no perceived need to defeat) and when producing long or unusually shaped parts. In such cases some managers stated they advocated defeat, perceiving this circumstance to be safe and acceptable e.g. it had been risk assessed. Hybrid machines (manual and CNC) were cited as a particular reason to defeat interlocks due to the perceived lack of flexibility on these machines. It should be acknowledged that this perceived lack of flexibility might have been due to a lack of understanding of the machine functionality. There was also considerable confusion over legislative/regulatory requirements for these machines e.g. do the guards have to be in situ at all times or only when operating in CNC mode.

A further issue encouraging operatives to defeat was the desire to avoid having to restart a programme. For example, when stopping the machine to remove swarf or deburring many machines cannot be restarted mid-programme; the machine will automatically go back to the beginning of the programme. This perception may be due to a lack of understanding fully the machine functions. By defeating the interlocks and opening the guards whilst the machine is running, operatives can avoid the time costs incurred of restarting the programme.

Job related reasons for defeating related to the opinion that manufacturers produce machines with impractical guards. Consequently, operatives perceived the job cannot be done unless the guards/interlocks are defeated, or is easier and quicker to do with interlocks defeated. Defeating was therefore perceived as a means to avoid stress and frustration. Defeating was also perceived as more likely to occur when setting up due to the fact that operatives only get one chance to set a machine up correctly. However, such defeating activity was perceived as safe, the perception being that operatives would not run the machine (other than when setting) with guards open, or stand at a safe distance.

"It's where you're doing a one-off in this hour, and in the next hour you're doing one of those where you need flexibility, whereas if you've got repetitive processes it's very easy to guard.... " (MAN 4)

" *some of the jobs are so unusually shaped you just would never do it* [without defeating]*...part of what we do as a company is produce parts that are very long and we have to take the guards off to do it….But we've always looked at it and risk assessed it and we know what's going on…I mean it's part of what we do, I mean we could never buy a machine big enough to do what we do."* (MAN 3)

"And by the time you've got the job done, you'd be extremely frustrated...Stressed too...Closing doors and pressing buttons..." (OP 6)

"And they just seem to think that the job can't be done any other way..." (MAN 6)

"…if you open the doors then you'll have to start from the beginning again...If you interfere with the doors you can stop the machine, shut it and carry on from where you've just opened the doors." (OP 2)

"99% of the problems are in the setup… You don't get two 'goes…" (OP 1)

Managers and operatives discussed perceived time pressures to defeat. Both groups speculated that pressure to get products out quickly could be a motivating factor for defeating interlocks in other companies but denied that in their organisation operatives would defeat because of productivity pressure. Whilst acknowledging that operatives would defeat interlocks to make the job easier/quicker, managers denied putting operatives under pressure to do this. Consistent with this claim, operatives stated they did not feel under pressure from their management, any pressure appeared to be self-imposed e.g. to do the job correctly. It was suggested that in organisations where performance bonuses are given this may motivate the defeating of interlocks. Finally, whilst time pressures were not cited as a major issue in participant organisations, tight timescales to meet customer requirements were acknowledged as a possible reason to defeat by one manager. Time pressures related to having to restart machines, and the time taken to reinstate guards e.g. if they had been removed to set up a job.

"…they certainly wouldn't be under pressure to do it, they wouldn't be told to do it. I would take a very dim view of that happening but it's assessing a suitable risk in their day to day job. So if a day to day job for a machine that we've purchased means that there's something in the way that's preventing them from doing the job and they've assessed the risk then I think that's probably the pressure, its ease of doing the job". (MAN 4)

"No it won't be through production or anything like that where I would say we've got so many parts to get through in 'x' number of time that's not what we do." (MAN 3)

"Yes I think speed setting...I mean instances where we have jobs where we have to take it off [the guard], sometimes it's just the time to put it all back on, people just, time pressures really…" (OP 3)

"This company and other companies might be different because we're not pushed in any way for time, we're not on piecework so most of the stuff we do is convenient for us." (OP 4)

"Just to make the job right...Get the job done…I wouldn't say it's a pressure but it's...you don't want to put the job in wrong." (OP 6)

4.3.2.3 How to defeat interlocks

Managers and operatives were asked for their opinion/experience of defeating interlocks. Both managers and operatives were aware of the practice of defeating. A variety of tools/ techniques for defeating were discussed. One manager however did state that he was unsure how workers defeated interlocks.

Dummy and override keys (keys placed in the machine causing it to sense a circuit and carry on running) were the most common tools used. Other techniques cited involved using screwdrivers to physically remove the interlocks, washers to lift guards past the interlocks, gaffer tape placed around the micro switch that senses when the guards are closed and simply electronically disconnecting interlocks e.g. turning off at the switch. One group also commented on the use of magnetic pieces/fobs to defeat interlocks on lathes. All operative groups contained supervisors who were fully aware of, and participated in the use of such defeating techniques. Several groups discussed supervisors providing keys to operatives and stated the use of override keys was only after discussion with the supervisor. However it was emphasised that such practice would only be for setting purposes. Managers were also perceived by operatives to be aware of the practice and the tools/techniques employed.

The perception was that such tools/techniques are readily available. Organisations reported accessing keys to defeat from machine manufacturers/suppliers/service engineers. It was reported that operatives/supervisors would often make their own copy of such keys or improvise with alternatives made in-house.

It was suggested that all operatives knew how to defeat interlocks. The primary knowledge source of how to defeat was considered to be experience - learning from experienced operatives on the job and the operative's own experience of using the machine. Engineering knowledge and common sense were also felt to help operatives identify how to defeat. It was even suggested that engineers would relish the challenge of defeating some interlocks.

Regarding ease of defeat, the general opinion was that defeating interlocks is straightforward, quick and easy to do and guards can also be removed from machines quickly and easily. Differences in ease of defeat were noted however according to machine type, particularly for modern machines. Newer machines were noted to be less easy and more time consuming to defeat – e.g. interlocks are built into doors and cannot be accessed. However it was felt that the interlocks on some modern machines are still relatively easy to defeat.

> *"It's quite easy to cut the machine a key; you just use the one that's in the machine as the pattern."* (MAN 1).
>
> *"…but the key is not kept in the lock, it's kept off the machine, so [operative] couldn't just go to the machine and turn the key and be into it, he's got to come to me [supervisor] and ask where the key is..."(*OP 5)
>
> *" …they can learn how to disable that because that's the way Bob's been doing it for twenty years."* (OP 3)
>
> *"…it's all the more of a challenge...It's like the Rubik's Cube isn't it…Tamperproof bolts? Relish the challenge. It's like a safe breaker isn't it, you know."* (OP 7)
>
> *"I mean they will come off easily so if we do need to get them off we can get them off easily..." (*MAN 3)

4.3.2.4 Understanding of machine functionality/operating modes

Some responses previously discussed e.g. defeat due to lack of flexibility of machines and not being able to stop programmes mid cycle may imply that there can be a poor understanding of machine functionality. However, managers were of the opinion that their own understanding of the functionality and operating modes of machines was good. Operatives also perceived managers to have a good understanding and knowledge of the machines. It was considered necessary and appropriate for managers to have this understanding. The primary source of managers' understanding was considered to be previous time spent as operatives/machinists themselves (apprenticeships served, training and shop-floor experience). However, such experience was perceived to possibly contribute to the defeating of interlocks due to the likelihood that managers had defeated interlocks themselves as operatives and were accepting/understanding of the reasons for doing so.

Across the interviews, managers considered their operatives to be fully equipped (have a good understanding and the appropriate skills) for general machine operation as well as the operation of specific machines. Operatives shared this confidence in their own knowledge and skills. This knowledge/skill was considered to come from several sources; initial training (apprenticeships, college courses, induction training), supervision of new recruits, experienced operatives mentoring and cascading knowledge, hands on experience, machine-specific training from suppliers/manufacturers, user and maintenance manuals and advice from manufacturers. Whilst on the job experience was not always machine-specific, operatives did not necessarily perceive this as a problem. There was a perception that lessons could be learned across machine type. Generally, on the job supervision and learning from experienced operatives was the primary training medium provided within companies; no specific in-house training was typically given, although one company did have an in house training resource. It was suggested that apprentices would learn good practice in college but pick-up bad habits on the job. Training was not usually given on new machines when replacing machines operatives already knew how to use, or when second-hand machines are procured.

The quality/quantity of machine specific training delivered by manufacturers/suppliers appeared to vary depending upon machine type and supplier. This ranged from a 5-day course that some operatives attended and then cascaded down to a 1-day in-house training for all. The perception amongst managers and operatives was that this type of training placed emphasis on how to operate machines and less on going through the safety systems and their purpose. Machine-specific training was also viewed as unrealistic e.g. conducted with interlocks always in place. Across managers and operatives the perception was that the training operatives receive is sufficient. Most managers reported formally documenting operatives training and supervision, however the competence of operatives was generally assessed informally on the job. Finally however, no refresher training was reported as being provided by any organisation, nor did managers or operatives regard it as necessary.

"*Well the MD does, yeah, because he's come off the machines.*" (OP 6)

"So when you go into an area your knowledge would be passed on by the existing people...passed on in a, sort of in an informal mentoring on the job capacity". (MAN 4)

"Yeah. I mean they're taught in the college how it's supposed to be done with the guards on, the interlocks whatever and then they come in here and it's different." (MAN 6)

"*It is up to the supervisors to decide when an operative is ready and competent to use a machine.*" (MAN 1)

I don't know if that'd [refresher training] make any difference at all actually...No, most people would think it's a waste of time..." (OP 3)

4.3.2.5 Standards and guidance

Managers accessed standards/procedures and guidance from several sources. Machine manuals provided by machine manufacturers/suppliers were the primary source of information. HSE website and inspectors were also cited as a source of guidance and information for managers. Several managers also reported using external companies/consultants for health and safety advice and updates on legislation.

With regard to the suitability of machine manuals managers held varying opinions. Some managers felt that manuals were generally easy to understand; others considered them not to be. However, it was noted that managers would not typically use machine manuals or be familiar with them; they were considered primarily for supervisor/operative use. Consequently there was a lack of clarity from managers as to whether manuals contained safety information or not.

Operatives also cited machine manuals as a source of information for operating procedures/standards and guidance. Opinions of these manuals varied e.g. depending upon machine brand. Some operatives stated manuals were not user friendly e.g. operational information was difficult to understand and there were too many manuals per machine (e.g. programming, maintenance and operating manuals). Manuals were regarded as easy to understand when operatives are familiar with the machine however.

A further criticism related to a perception that manuals are not written in practical terms and do not reflect how the job is carried out in reality. In general manuals were not reported as used often. Operatives tended to rely on each other (experienced workers passing on knowledge to less experienced) or would call manufacturers for advice if there were any problems with the machines. Safety information in machine manuals was felt to be limited. Furthermore, operatives were of the opinion that the health and safety information contained in manuals is common sense. Manuals were generally only consulted for specific reasons e.g. programming issues.

> *"There must be, there must be…but it was so long ago to be honest I read the manual that I probably couldn't tell you anyway."* (MAN 3)
>
> *"No, they're not user-friendly; they're usually in a foreign language [i.e. too technical]… But these machines come with twenty manuals...It's quicker just to phone service up and ask them probably."* (OP 2)
>
> *"As safety goes, the manual would be written in a way that makes it possible to do the job, but in reality it's not."* (OP 6)

4.3.2.6 Worker consultation/involvement

Participants were asked how their organisation consulted with and involved operatives about machine safety specifically, and health and safety in general. *N.B. Responses here relate also to Section 4.3.1.5 (Communication of health and safety).* Both managers and operatives considered it important that operatives' concerns were noted and acted upon, and mechanisms were in place to permit this. Worker involvement was recognised as an important way of improving safety. Some organisations reported having weekly meetings involving operatives during which issues are discussed and improvements suggested. Generally however consultation/involvement was reactive as opposed to proactive.

Structured, regular consultation and involvement was limited across participant organisations. Often there was no formal medium for direct communication between management and workforce. In most participant companies the process of raising concerns was informal. Supervisors and safety representatives acted as intermediaries on an ad hoc basis e.g. workers would raise issues/concerns to their supervisor/safety representative who would then discuss these at the health and safety meeting with management. In one organisation, operatives had been offered, yet declined, the offer of a health and safety committee. Despite a lack of formal involvement there was a general perception however that any issues or views could be addressed informally. There is an important link here to drawn with the points discussed below regarding machine procurement. Some operatives raised the point that they would welcome more involvement.

> *"I don't need the formal meetings so much… you know if one of us sees something wrong we can instantly bring it up and deal with it.*" (MAN 3).
>
> *"We were trying to set up a safety committee but I don't know, they're not keen...They don't want the hassle I think, the operatives. I think they would just rather that I did it."* (MAN 6)
>
> "*Can raise issues with the shop floor reps which are then raised at H&S meetings."* (OP 2)
>
> "*And I think the more people that you can get involved the better because you actually empower that individual and make him feel important and part of the process…" (OP 7)*

4.3.2.7 Machine procurement

Managers were asked about the procurement of CNC machines and the reasons for their procurement decisions. Managers reported purchasing both brand new and second-hand machines. Brand new machines were generally purchased direct from suppliers/manufacturers, second hand machines from dealers. When asked about their reason for choosing a specific machine, generally manager's decisions were driven by the functionality and capability of the machine; machines were purchased primarily for their ability to meet workload requirements. The price of the machine was another factor taken into consideration. Whilst more expensive machines were regarded as having safety features built-in, safety was not cited as a primary consideration, instead safety features were viewed as an added bonus. Generally, workers were not involved. Only one company reported workers having any direct involvement in procurement decisions.

> *"We're looking for functionality, being able to hold close tolerances and multitask, do numerous operations. But the main thing we're looking for is productivity…"* (MAN 2)
>
> "*The workload, the workload...It would all be down to workload.*" (MAN 3)
>
> *"…they need to be comfortable with it. Quite often we would send the people to the machine tool people to have a look at it in their environment.*" (MAN 4)

4.3.3 Reinforcing factors

4.3.3.1 Benefits associated with defeating safety interlocks

Managers and operatives were asked about the perceived benefits of defeating interlocks. The themes that emerged were similar to those that were identified regarding the reasons for defeating interlocks (Section 4.3.2.2.). Key points that emerged included making it possible/easier to do the job and saving time. Therefore, to avoid duplication, responses have not been repeated here. However, in order to ensure a thorough account of the research, full responses to this specific question may be found in the Reinforcing section in Appendix 7.

4.3.3.2 Perceived consequences of using interlocks at all times

A number of themes emerged from the management interviews and operative focus groups regarding the consequences of operating safety interlocks at all times. These themes overlap with issues identified regarding the reasons for defeating safety interlocks. For instance, taking longer to complete the work and not being able to carry out some types of jobs were some of the most common issues discussed. However, these issues are also briefly discussed here to highlight the perceived consequences for the organisation of using interlocks at all times, particularly in terms of potentially not meeting customer deadlines and reduced profitability.

Managers and operatives noted that if machines were operated with safety interlocks at all times, jobs would take longer to complete, and potentially many jobs would also be 'scrapped' as components would not be manufactured to the specified standards. Specifically, it was suggested that operatives would need to stop the machine to visually check the machining process and make sure that no mistakes had been made at the setting up stage. Stopping the machine would translate into 'time lost' as the work would have to start from the beginning. In addition, operatives also noted that having the interlocks on at all times would mean that some types of work would be impossible to carry out, such as manufacturing components that were too big and/or long for the type of machine used.

Taking longer or being unable to carry out jobs, as well as 'scrapping' work was perceived as costly for organisations for two reasons. Firstly, potentially costly materials would be wasted, and secondly, delivery dates for customers could also be affected as jobs would take longer to complete. One manager discussed these issues in the context of increasing pressures from customers to complete jobs more quickly. Interestingly, another manager observed that operating machines with the safety interlocks on at all times would be safer for employees but costly for the organisation.

"I mean we would do 90% of it [the job] but there would be the 10% that we couldn't." (MAN 3)

"I think a lot of scrapped jobs ...Because they need to see the job setting up and also, as I said earlier, about the internal threads, that they need to remove the swarf...I think if the swarf builds up and they can't take it out then the thread won't be able to turn; they won't be able to complete the cycle...and then the job would be...You'd have to scrap it and start again." (MAN 6)

"I get an odd big job now and again where it is, I suppose really it's physically too big a machine but you can do it on there if you remove the guard to do it." (OP 4)

"The scrap rate would go sky high for a start." (OP 6)

"You know, I think because people are under pressure to get things done that's, that's, you know, you are driven; I mean nowadays, I mean industry nowadays lead times are short, customers want jobs quicker." (MAN 1)

It should be noted that a contradictory view was expressed by operatives in one focus group where they described that they always operated the machines with the interlocks in place; and that the use of interlocks did not adversely impact on their ability to do the job. Given that this company (as per the research criteria) had previously received an HSE notice for defeating interlocks it is important to recognise that this response **may** have been due to social desirability bias (tendency of respondents to answer questions in a manner that will be viewed favorably by others). This bias was not evident to researchers across the other responses given by the focus group participants.

4.3.3.3 Organisational response to incidents related to defeating interlocks

Managers and operatives were asked how incidents of defeating safety interlocks were dealt with in their respective organisations. In the majority of cases, organisations had a formal disciplinary procedure that would be followed. This would typically include a verbal warning, followed by a written warning if the incident re-occurred, and ultimately dismissal.

> *"...That would involve a verbal warning, of which if you amount up enough then you eventually get...well I think it's two verbal, one written and then you're dismissed for breaking company rules..." (OP 1)*
>
> *"'It would be definitely dealt with a verbal, probably a verbal warning/first written warning, if anything, and more so if there was any injury, anything like that, either to that person or any other person, you know, I mean we've never come across that as such, because of interlocks not being used so we haven't went down that route but I'm sure we'd take it very seriously, definitely."* (OP 5)
>
> *"They would be on the disciplinary route, they'd get a verbal warning to begin with and a refresher on training and why you're not to defeat interlocks [...] The disciplinary procedure is in the handbook yes so, and obviously a repeat occurrence of the same person doing the same thing you know you'd just follow the disciplinary route ultimately... instant dismissal."* (MAN 2)

Among the companies that had a formal procedure in place, there appeared to be variations in the ways disciplinary procedures were implemented. In some cases all incidents that involved defeating safety interlocks were treated as 'gross misconduct', whilst in other cases such incidents were considered as 'gross misconduct' only if they had resulted in serious injury. However, no actual incidents of disciplinary action being taken were reported. Rather there was a recognition that these were the type of circumstances where disciplinary procedures could be used. In two organisations, however, there appeared to be no formal procedures in place for dealing with incidents where interlocks had been defeated.

In many cases, defeating was accepted as 'normal' practice with disciplinary procedures followed only under certain circumstances. For instance, operatives in one organisation reported that interlocks were routinely defeated for setting and machine cleaning tasks. Disciplinary procedures were reported as only likely if the operative had not informed the supervisor that he was taking the key to defeat the interlock, and if interlocks were defeated whilst the machine was running. Operatives in another company felt that management were aware that safety interlocks were defeated but 'turned a blind eye.' Managers were perceived as appreciating the difficulties that operatives would face if they had to use the interlocks to carry out their job, and for this reason operatives were not reprimanded for defeating interlocks. Some participants reflected on their previous experience for working in other organisations, and noted that it was common practice for the use of safety interlocks to not be enforced and for management to not challenge these practices.

"Well we've had that situation, we didn't do anything about it, so we just put it right...But it wasn't deemed to be a serious problem so it wasn't treated as a disciplinary issue or anything like that. It was just done by a cell leader looking at the area and advising." (MAN 4)

'It is accepted that there are times during maintenance or setting where we need, maybe need to override it.' (MAN 1)

"But we know there's instances and we do independently risk assess for jobs where we know we have to take it off, because we physically can't do the job with the guard in place… we accept that there's instances when that does have to happen." (OP 3)

"It's just normal practice...(name of Managing Director omitted) knows all the machines that are defeated." (OP 6)

4.3.3.4 Ease of detecting when interlocks are defeated

Managers and operatives felt that it would be difficult to detect that safety interlocks had been defeated (unless the machine was in operation with guards/doors open). This was because when the machine was in operation and the safety interlocks were in place, then the doors/guards should be shut. Thus, if the machine was in operation with the safety guards open, it would be obvious that interlocks had been disabled. However, if the machine was not running, it would be difficult to detect whether the safety interlocks were disabled or working as they should. Moreover, safety interlocks could be disabled even if a machine was in operation with the doors closed. In such cases, it would be difficult to detect if the safety interlocks were defeated or indeed functioning properly, unless one attempted to open the doors of the machine (which should not open if the interlocks were on).

It was also noted that it would not be possible to detect if a safety interlock had been defeated from a distance and it would require a close visual inspection of the machine. In most cases, there were no warning signs that a safety interlock was defeated. In one organisation, operatives mentioned that an alarm would sound to indicate that safety interlocks were disabled.

Difficulties in detecting whether safety interlocks had been disabled were more relevant for older machines. For newer machines, if the interlocks were defeated or were faulty, the machine would not run and, the control panel would also indicate that there was something wrong with the interlock. Some managers highlighted the challenges in enforcing the use of interlocks. Specifically, although supervision could help minimise incidents where machines were operated without interlocks, it was suggested that workers could still disable the interlocks when they were not supervised. Finally, it should be mentioned that some operatives mentioned that no checks were routinely carried out before operating machines to determine if the interlocks were enabled.

"The next operator on wouldn't necessarily know because he, you know unless he was doing things that required the interlock to be defeated, like opening the door whilst the machine was running…But if he was just operating in a normal manner, closing the door at the usual time and then running the machine at the usual time then he wouldn't necessarily know." (MAN 2)

"If the guards open and the machine's open it's blatantly obvious, but if the machine wasn't running you wouldn't be able to necessarily tell." (OP 3)

"… there's no warning sign to say my locks have been defeated. Nothing at all." (OP 7)

4.3.3.5 Commitment to health and safety

The interviews and focus groups also explored managers and operatives' perception as to whether their respective organisations were committed to health and safety. Participants were prompted to provide specific examples of how their organisation demonstrated commitment to health and safety. A number of positive practices were identified, however these were not shared among all organisations.

Specific examples were provided in several organisations where managers and supervisors carried out periodic health and safety inspections, including checks to ensure that safety interlocks were enabled. The frequency of these audits varied across organisations and ranged from one audit per week to one audit per month. However, in one organisation, these audits were treated as a 'tick-box' exercise, rather than as an opportunity to identify incidents where the safety interlocks on machines had been disabled. It should be mentioned that in that organisation, the defeating of safety interlocks was considered as 'routine' practice. In another organisation, carrying out checks to ensure that safety interlocks were enabled was seen as a shared responsibility between management and operatives. For instance, in addition to managers' periodic checks, operatives were asked to complete 'work route inspection cards' (referred to as 'job tickets') to ensure that safety interlocks were in working order. Work route inspection cards were also used as a means of ensuring that interlocks were fully restored if they had been de-activated. This was particularly the case for older machines, as the safety interlocks on newer machines were perceived as harder to defeat.

> *"...to encourage best practice we're looking for all our employees to actually pass on safe interlocks to the next operator by signing that, whilst they're working the machine the interlocks have been checked and they're good.."* (MAN 2)
>
> *"I ensure all the guards are on the machines once a week and make sure they all work. I know there's instances where they will be removed to do a certain job and that, but I make sure every week the guards are there, they're on the machine and they're working."* (OP 3)
>
> *"Well, as the cell leader I've got a book down there and every month I have to fill in a health and safety sheet...So it's a checklist of all the possible things that could happen from a fault with the machine that I need to spot and sort out to oil on the floor ..."* (OP 4)

Managers also discussed actively trying to promote an 'open' culture where operatives felt supported for raising safety concerns. This was also concurred by operatives who discussed that they were able speak up if they were asked to do a job that they felt was unsafe. Operatives also discussed the supervision of apprentices and inexperienced workers as another means by which their respective organisations demonstrated health and safety. For instance, supervisors made sure that apprentices used the correct PPE and were aware of the dangers of working with machines. Examples were also given of pairing inexperienced workers with experienced ones when operating CNC machines.

> *"I've got an apprentice for example, I'd make sure he's got some safety glasses in his pocket, he's got safety boots on, he's got his overalls on, and he understands the dangers on our particular section and it gets logged on a little sheet."* (OP 4)
>
> *"...we always try and have that policy here, to have somebody with experience rolling alongside somebody with a little bit less experience."* (OP 5)
>
> *"I will praise them for bringing issues to my attention, there's more of a like, 'we've got a problem here' and then bringing it up they would be more likely to get praise for that to be honest with you."* (MAN 3)

However, not all participants perceived their respective organisations as being committed to health and safety. There was one exception where operatives in one focus group felt that their organisation, and particularly senior management, was not committed to health and safety. Specifically, the Health and Safety Manager in the organisation was described as being committed to health and safety but receiving little support from senior management. Despite this, some improvements were noted in the organisation, e.g. hard hats, which operatives were expected to wear on the shop floor, and safety notices reminding operatives of machine hazards.

4.3.4 Suggestions for improvement

Participants were asked for their views regarding what could be done to promote safer working practices when operating CNC machines, and raising awareness of the risks of defeating interlocks. Several suggestions were made regarding the role of machine manufacturers, organisations and the HSE in helping to promote safer working practices.

Design & Manufacture: Several managers highlighted the important role of both machine designers and manufacturers, and the need to work together to identify ways in which machines could be improved to reduce the need to defeat safety interlocks. One suggestion focused on the need for manufacturers to place more emphasis on the purpose of safety systems, such as interlocks, on machines as part of the training they deliver; the emphasis of the training appeared to be more on how to operate the machine rather than the safety systems and why they are in place. It was also suggested that manufacturers should consider the use of guards that are more damage-resistant to help improve visibility of the machining process. Interestingly, however, operatives in one organisation felt that, although the use of better quality guards would be an improvement, the machine guards should still be open.
Video Camera: Adding video cameras on CNC machines to allow operatives to visually check the machining process, without having to defeat interlocks, was another suggestion provided. However, it was noted that video cameras would also need to be robust so that their quality did not degrade quickly (much like with the quality of the safety guards).

Machine programming and error messaging: Other suggestions focused on improving machine programming and design. It was suggested that manufacturers should incorporate better programmes that would allow operatives to resume work where it was left off, when having to stop the machining process, rather than having to start from the beginning. Additionally, machines should have a “built in” automatic probing system to help negate the need to defeat interlocks during the setting up process. Some operatives also discussed the potential use of error messages to make the detection of interlock overriding easier; for instance, machines could have error messages to indicate that the safety interlocks had been disabled, and prompting operatives to enable them. Alarms on machines indicating when the machine doors were open were also suggested.

> *'I think they [manufacturers] should add in a little block… going over the safety aspects of the machine. What really is expected of you safety wise but what aspects are built into the machine and the consequences of overriding those.'* (MAN 1)
>
> *“…it is a vision process that needs to be addressed and unless they can find something that isn’t going to get damaged so easily on the machine, you know, there is no other way that it can be done.”* (OP 1)
>
> *“Why can’t you write a programme in a machine to do what we want it to do and make, make things safer for the employees?’... So if they interrupt the programme midway so it’s not going to go back to where it starts.”* (MAN 6)
>
> *“Or even, I would imagine quite a fairly simple bit of programme, they might put an error message on the screen ‘guards disabled...”* (OP 3)

Guidance: In addition to the role of machine manufacturers and designers, some managers suggested the development of a good practice document (similar to the 18001 standard but shorter) that would specify the types of safety management systems that organisations should have in place. One manager suggested that this could take the form of emails to communicate the risks and consequences of operating machines without safety interlocks.

Tool access: Another suggestion focused on limiting access to tools, such as keys, that would enable operatives to defeat safety interlocks. It was suggested that regulations could be introduced to legislate against and therefore restrict access to tools. Further, the issue regarding whether safety interlocks should be used on semi-CNC machines was perceived as an area that HSE should clarify in conjunction with machine manufacturers.

*Duty of care***:** An alternative view, expressed by some operatives and one manager, was HSE could not do anything more to promote safer ways of working. This was because workers were more health and safety aware than they used to be and there was already a lot of regulation in place. For others, the responsibility seemed to rest on the employer to ensure there were effective safety management systems in place to prevent the occurrence of safety interlocks being defeated.

> *"I think you would have to force businesses to do it [limiting access to overriding keys] through legislation because with all due respect there is a number of companies that would try and cut a corner…they're under pressure to make money, to get the goods out the door."* (MAN 5)
>
> *"I think that a lot of it is also down to commonsense and, you know, and just people...and I think they've done good things as well and I think that people are more aware and more safety conscious now than what they used to be."* (OP 1)
>
> *"... I don't know other industries but certainly in engineering they're[HSE] seen as more policemen […]"* (MAN 4)
>
> *"I don't know that the HSE can specifically do anything to help raise the issue to a higher level…nowadays if you've got a company that's defeating interlocks then they probably haven't got a very robust management system anyway."* (MAN 2)

Competency: Specific suggestions were also provided regarding steps that organisations could take to promote safe working practices. Training and competence in using CNC machines, and effective supervision of inexperienced operatives until they developed the necessary competence was viewed as crucial. In relation to training, one manager suggested that there should be funding schemes from government to help support small organisations in training workers on CNC machines as manufacturers charge a lot of money (about two to three thousand pounds for 2-3 days' worth of training).

Prompts: Finally, there were mixed views regarding the effectiveness of initiatives, such as communication campaigns, or the use of signage on site, to help raise awareness and communicate the importance of using safety interlocks. For instance, some managers felt that signs used on site tend to be ignored by workers, unless they are changed constantly to maintain interest. On the other hand, some operatives suggested that vivid imagery and videos could be used (as part of a toolbox talk, for example) to promote safety messages of what could go wrong when working with CNC machines, especially among apprentices.

"My apprenticeship...they would frighten you with pictures of people with no fingers and no eyes and allsorts and some of it stays...I think old fashioned ideas like that sometimes perhaps still do work on young people, impressionable kids that are out of school and they've gone into engineering..." (OP 4)

"My view on signage is it gets ignored after a while...It does become wallpaper and the only way I think signage works is if you're constantly changing signs [...] I couldn't even tell you half the signs here are. I know that there's signs gone up there but I couldn't tell you where they are in the workshop." (MAN 3)

4.4 SUMMARY OF RESULTS

This research has provided a number of valuable insights regarding the prevalence and the factors that influence the defeating of safety interlocks.

- *Widespread practice:* Regarding the extent and prevalence of safety device manipulation, the findings of this research suggest that bypassing safety devices is viewed as the norm across the UK engineering industry. It must be acknowledged that this research cannot provide robust evidence that the practice is widespread. This was small-scale qualitative research conducted with organisations that had previously defeated interlocks. Many types of machines and protective devices were identified as commonly being tampered with. Amongst the small number of companies who participated semi-CNC machines were identified as being a particular type of machine commonly defeated. Operatives use a variety of different tools and techniques to defeat interlocks/guards.

- *Activity type:* Overall, the current findings support and expand on the Phase 1(see Annex Report) literature review findings regarding the types of activities that are associated with defeating of safety interlocks. Key activities associated with the defeating of interlocks/guards were setting and programming, as well as during troubleshooting and maintenance.

- *Hybrids:* Additionally, Phase 2 findings also identified that safety interlocks are also more likely to be defeated when operating hybrid machines (i.e. semi CNC machines), and during activities such as proving, drilling, de-burring, drilling, swarf removal, removing/replacing collet, and machining inside pipes.

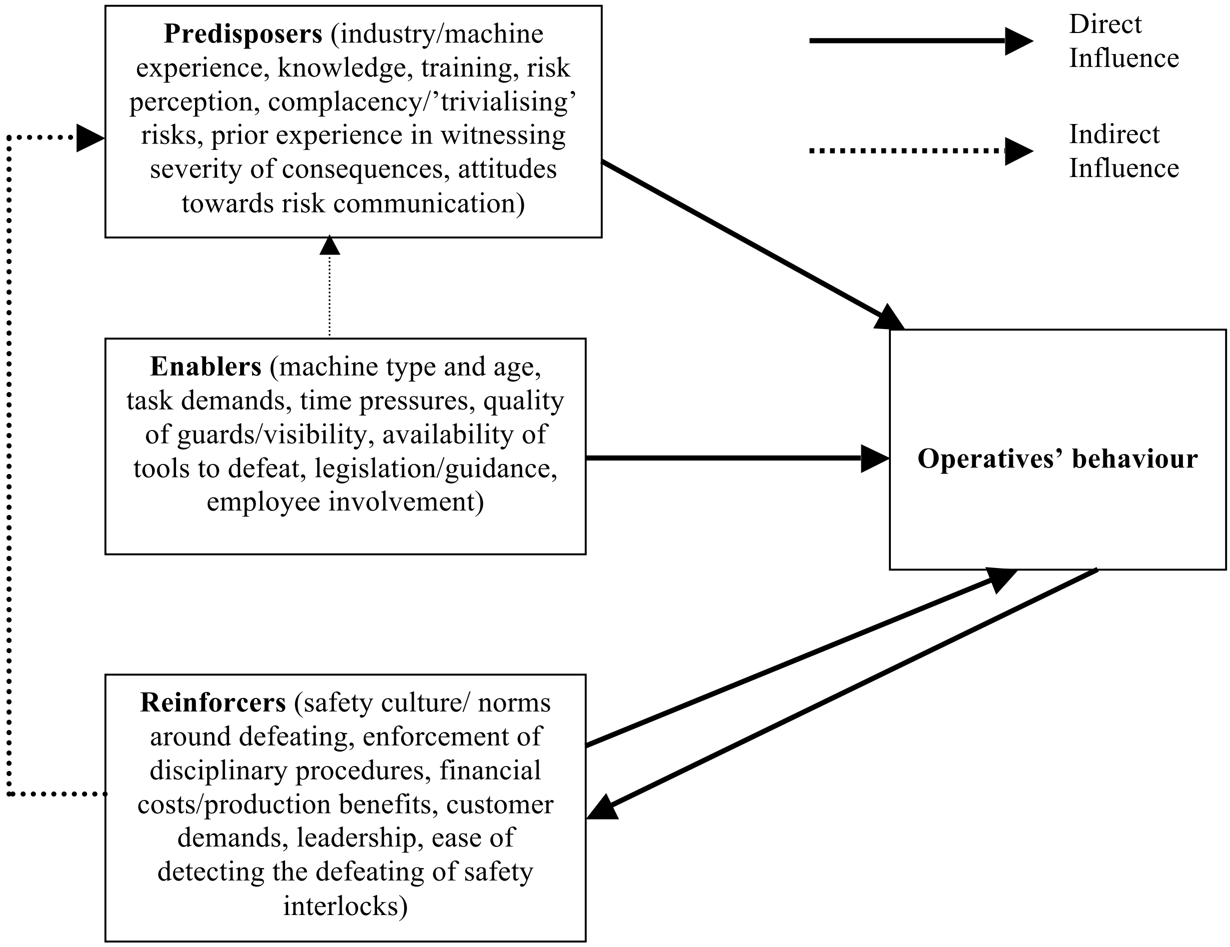
- *Factors influencing behaviour:* Three overarching sets of factors were identified as influencing operative behaviour in the context of defeating interlocks/guards. Predisposing (characteristics of the individual that help or hinder the uptake of risk controls), Enabling (objective aspects of the environment/ system that block or promote the uptake of risk controls) and Reinforcing (environmental features that reward or punish compliance-related behaviour). The findings of the current research imply that all three factors influence operative behaviour.

- *Predisposing:* The findings support those of Phase 1 (see Annex Report) suggesting that **low risk perception, and awareness of personal susceptibility** to the severity of risks associated with defeating of safety interlocks are important predisposing factors. Specifically, the findings from the Phase 2 interviews and focus groups suggest that, although experience and training provided an appreciation of the risks involved when defeating safety interlocks, there was a tendency, particularly among experienced operatives, to trivialise and perceive these risks as 'common sense'. There were mixed views regarding the effectiveness of risk communication approaches, such as the use of visual signs, to increase awareness of the risks associated with machine operation. It was suggested that this type of risk communication may be effective for apprentices, but less so for experienced operatives as risks were regarded as 'common sense'.

- *Enabling:* Poor **worker-machine interface** emerged as a crucial enabling factor influencing operatives' decisions to defeat safety interlocks. Consistent with the findings from Phase 1 (see Annex Report), poor visibility, difficulties in accessing the job, as well as saving time due to slowing down of the machining process when safety interlocks were used, were commonly cited reasons for defeating interlocks/guards. Further, task requirements, such as the ability to manufacture 'one-off' components, as well as unusually shaped components, also facilitated the need to defeat safety interlocks. The ease of defeating safety interlocks, especially on older machines, and the accessibility to a variety of tools to remove safety interlocks/guards also emerged as important enabling factors. The safety interlocks on semi-CNC machines (combining manual and CNC modes) were more likely to be defeated due to the perceived lack of flexibility on these machines, and due to confusion over guarding requirements (e.g. whether guards had to be in place at all times or only when operating in CNC mode). This finding implies a lack of full understanding of the functionality of machines. In addition, most participating organisations lacked structured and regular consultation channels with operatives on health and safety; rather, the predominant means of raising safety concerns appeared to be informal.

- *Reinforcing:* Consistent with Phase 1 (see Annex Report) findings, **poor safety culture** and a lack of enforcement appeared to reinforce defeating practices. In several organisations, the defeating of safety interlocks was accepted as 'routine', especially for certain tasks. Management were perceived as 'turning a blind' eye to these practices. Although a number of positive health and safety practices (e.g. provision of PPE, health and safety signage and audits) were identified across several participating organisations, there was no evidence that the use of safety interlocks was enforced. This was partly attributed to the ease of defeating, as well as to the difficulty of visibly detecting when safety interlocks had been defeated. Although most organisations had formal disciplinary procedures in place, their enforcement was variable suggesting that there were no 'real' consequences for defeating safety interlocks. Financial/production pressures and customer expectations were also acknowledged as important influences on operatives' behaviours.

The key predisposing, enabling and reinforcing factors discussed above are illustrated in the PRECEDE model framework below.



- *Suggestions:* Finally, participants made a number of suggestions regarding the ways that safer working practices could be promoted. With regards to the roles of machine manufacturers and designers, it was suggested that they could consider aspects of machine design, such as the use of better quality glass and/or use of video cameras, to help improve visibility of the machining process. Additionally, the use of systems to warn operatives that the safety interlocks had been disabled, such as alarms or error messages, could also be used, as well as programmes that would allow operatives to resume work where it was left off, when stopping the machining process. Incorporating automatic probing systems would also help facilitate setting activities and reduce the need to defeat interlocks. It was also suggested that machine manufacturers could put more emphasis on the safety aspects of machines, particularly the purpose of safety interlocks, as part of their training to organisations for newly purchased machines. With regards to HSE's role, participants suggested that HSE could play a more advisory role in order to help support organisations to establish effective safety management systems. This could take the form of emails to communicate the risks of defeating safety interlocks and developing guidance on the types of safety management systems that organisations should have in place. Further, some participants suggested that there could be explicit legal sanctions aimed at preventing the use of certain types of tools for defeating interlocks. Finally, greater worker involvement, particularly in machine selection was suggested. Also, it was suggested that organisations could place emphasis on ensuring that operatives are adequately trained and competent in using CNC machines, and that inexperienced operatives are adequately supervised.

5. ISSUES FOR CONSIDERATION

This section focuses on providing issues to consider for improvements to the management and enforcement of operative behaviour (in the context of defeating interlocks provided to CNC machines). Issues for consideration within the following sub sections are based on the opinions and experiences of participants. These opinions support and expand upon Phase 1 findings (see Annex report).

The current research suggests that defeating interlocks is viewed as the norm across the UK engineering industry. It must be acknowledged that this research cannot provide robust evidence that the practice is widespread however. This was small-scale qualitative research conducted with organisations that had previously defeated interlocks.

Three overarching sets of factors (predisposing, enabling, and reinforcing) were identified as influencing operatives to defeat interlocks/guards. Having explored the influence of these three factors implies that there are strategies that could be considered to encourage behaviour change in the context of operatives defeating interlocks. It is helpful to consider any possible intervention in terms of the processes required to bring about behaviour change. Current research by behaviour change experts has identified eleven broad change processes (Abraham, 2012). Behaviour change strategies therefore should be developed with these change processes in mind:

- Facilitate behaviour change by prompting environmental (physical and social) change[23]
- Change risk perception
- Change normative beliefs about other peoples behaviour and approval of recipients behaviour
- Foster a positive behaviour related identity
- Change beliefs about the benefits and cost of behaviours
- Change feelings (or attitudes) associated with adopting or ceasing behaviours
- Enhance self-efficacy
- Change emotional states in readiness for action and during enactment
- Prompt and elaborate goals and goal priority
- Enhance social skills
- Establish behaviours using rewards

The above processes would be important when attempting to address the widespread nature of defeating interlocks and the key factors influencing this behaviour. Those appropriate are discussed below with specific reference to the defeating of interlocks.

5.1 EXTENT OF THE PROBLEM

<u>Change normative beliefs about other peoples behaviour and approval of recipients behaviour</u>

- Behavioural economics proposes that people; do things by observing others, want to be like those around them and are encouraged when they feel others approve of their behaviour (New Economics Foundation (NEF), 2005). Defeating interlocks appears to be a widespread phenomenon in the UK engineering industry. Such behaviour was regarded as the norm amongst managers, operatives and supervisors and often learned from the example of others. Consequently, the perception amongst many operatives was that the

[23] *N.B. In the context of occupational health and safety, changing the physical and social environment e.g. correct machine design, healthy safety culture is a crucial prerequisite to support and encourage safe behaviours (Bell et al 2001).*

behaviour is ‘approved’ by peers and managers alike. Therefore, strategies to shift the norm to compliant behaviour could be considered. This could include e.g. communication campaigns encouraging managers/supervisors/operatives to view unfavorably those who defeat interlocks. Similarly evidence suggests that the way in which messages are framed should be considered (NEF, 2005). E.g. posters stating 60% of operatives comply with safe procedure as opposed to focusing on the 40% who do not are more likely to encourage individuals to want to be in the larger group[24].

5.2 FACTORS INFLUENCING OPERATIVE BEHAVIOUR

5.2.1 Predisposing factors

Change risk perception

- Any effective behaviour change intervention must take into account receptiveness to change; there is a need to base risk communication on what individuals already know and believe. The current research found that managers, operatives and supervisors had a good knowledge and understanding of the risk from defeating interlocks. However, knowledge of the risk is necessary but not sufficient to bring about behaviour change. Participants failed to appreciate their personal susceptibility to the risk. Risk awareness without intent to comply requires persuasive risk communication (perceived as personally relevant by the audience). Although there was a good understanding of the potentially negative consequences of defeating interlocks, there was a sense that the risks were minimised if operatives were experienced. Risks from defeating safety interlocks were perceived as ‘common sense’, with experienced operatives perceived to be less at risk.

  In order to determine if this perception is supported by evidence, HSE statisticians conducted a search of available incident data to produce an estimate of the operative’s skill level (where this could be deduced from the text of inspectors' comments). Within the data, overall there were more references to experienced operatives than to inexperienced operatives[25]. It is important to note that this information came from free text with no constraints on the nature or means of expression of information. The results cannot therefore be considered as statistical data. Furthermore, there are no requirements to provide information on experience levels within incident reports. These caveats aside this data does have some value – indicating that experienced operatives are also susceptible to injury/accident. Ways to raise awareness of the susceptibility of risk to experienced operatives could be considered. Useful strategies could include personal testimonies/case studies from experienced operatives who have been injured, posters illustrating experienced operatives at risk of injury, presenting CNC injury statistics in terms of the operative’s level/years of experience. Positive framing of messages e.g. emphasising the benefits for the individual from not defeating interlocks such as a long productive, injury free life could also be used.

Change feelings (or attitudes) associated with adopting or ceasing behaviours

- Many managers and operatives held negative attitudes towards the guards on some machines. A common belief cited was that guards are impractical and can be inappropriate e.g. only placed on machines to cover the legal position of machine designers/manufacturers. Consequently such attitudes can influence whether or not

[24] N.B these are arbitrary numbers for the purpose of illustration.

[25] *Information taken from COIN (HSE enforcement and inspection database) between 2001/02 and 2010/11 found approx 3.5 cases a year. A reference was made to an operator's high skill level in about one case a year. Data taken from RAID database (pre-COIN records covering the period from 1996/07 to 2004/05) found a total of 15 relevant reports. In 6 reports the inspector referred to the operator as experienced, in 2 reports a reference was made to inexperience or unfamiliarity with that machinery. The other reports had no reference to operator skill level.*

operatives defeat interlocks in order to disengage such guards. Communication campaigns could be used to help managers and operatives change their attitudes – believe in the importance and necessity of guards from a health and safety perspective. A credible intermediary between machine designers/manufacturers and industry could help facilitate such attitude change. Manufacturers/suppliers are often the main contact for businesses in deciding what machines to put in place. Effort could be concentrated on building links with industry and machine manufacturers and suppliers to address the issues and concerns held by industry about the true purpose of guards.

- Related to the above point, there was considerable confusion over what is viewed as a grey area - the requirement for guarding on some machines. Participants stated removing guards due to a belief that they are not practical or uncertainty as to whether or not there is a requirement for them to be in place. Clear and simple guidance therefore would help to promote compliance.

5.2.2 Enabling factors

<u>Facilitate behaviour change by prompting environmental (physical and social) change</u>

- The most prevalent reason cited for defeating interlocks was poor worker-machine interface, hampering visibility, accessibility to the tools/job and ease of use. Lack of worker involvement, especially when selecting and procuring machines, may have exacerbated this. The current research identified many suggestions for improvement. The practicality of these suggestions could be explored further e.g. how machine design could be improved and engineering companies persuaded to buy machines with better safety features. Therefore stakeholders could for example consider organising workshops in order to explore collaboratively how to provide CNC machines with reasonably practicable, fit for purpose guards and interlocks, within the basic cost of the machine. The workshop could also explore, guard design and procedures for specific situations e.g. producing large/unusual shaped jobs.

- Nudges – designing rules, guidance and the environment in ways that gently ‘nudge’ people to do the right thing (Thaler & Sunstein, 2008) could be considered to change behaviour. Nudges operate on automatic behaviours e.g. habits and can be used to move unconscious habit into conscious action e.g. raise awareness of the fact interlocks have been defeated. The more novel and interesting nudges can be the more effective they will prove. Relevant nudges would include prompts/posters at the point of behaviour (machine interface) as cues to action of how to work safely and reminders of the consequences of not doing so. Other nudges could include colour-coding switches on interlocks, visual/auditory displays alerting machine user to fact that interlocks have been defeated and designing machines so they are difficult, awkward and inconvenient to defeat. An important caveat however is that nudges need to be routinely refreshed to avoid habituation.

<u>Change beliefs about the benefits and cost of behaviours</u>

- A commonly held belief was that the benefits of defeating interlocks outweighed the costs. Managers and operatives acknowledged that if machines were operated with safety interlocks on at all times, they may fail to meet customer expectations; jobs would take longer to complete, and many jobs would be ‘scrapped’ as components would not be manufactured to the specified standards. The benefits of defeating interlocks were also for convenience (being able to work quickly/easily). For example, by defeating interlocks they avoid restarting programmes mid cycle, can prove work, save time reinstating guards etc. The findings from this research have highlighted programme stop and automatic probes as useful aids. Some machines already possess these facilities so encouraging and supporting operatives to develop a greater understanding of the functionality of their machines would prove beneficial. Further cost-effective strategies to make the safe way of working the most beneficial (easiest, quickest and most convenient) could also be explored.

Enhance self-efficacy

- The various suggestions made above will not change behaviour unless operatives have self-efficacy (believe they possess the necessary skills/ have the necessary control to adopt the safe behaviour). In general, managers and operatives believed they had a good understanding of the functionality of their machines however this may not have been actually the case. There was evidence of a lack of understanding of functionality e.g. claims of lack of flexibility in programmes. There appeared to be limited formal in-house training and refresher training was neither provided nor viewed as necessary. Training provided for specific machines focused primarily on operating modes, not safety or the use of interlocks/guards. Therefore, the provision of machine training specifically focusing on interlocks and guards could be considered. Additionally, strategies that sustain knowledge and skills are crucial (Fleming & Lardner, 2002). Without properly looking at how safe behaviour is to be maintained, it will fizzle out. Strategies such as refresher training, toolbox talks, communication campaigns at regular intervals and on-going observation and feedback are therefore important.

Prompt and elaborate goals and goal priority

- Interventions need to focus on enabling managers and operatives to implement change through planning. Planning is an important element of the behaviour change process. Planning in advance when, where and how one will complete a goal (e.g. change a behaviour) will lead to greater success. Creating an "implementation intention" is one approach (Gollwitzer & Brandstätter, 1997). Implementation intentions help people initiate working towards their goal and help make the process feel automatic over time. Managers and operatives could consider how they and their operatives can plan in detail how they are going to improve compliance and provide behaviourally specified guidelines to support this process (the correct use of interlocks and guards). Planning could include worker involvement in developing risk assessments/method statements and incorporating safe behaviour goals related to interlock/guard use in personal objectives and performance reviews.

5.2.3 Reinforcing factors

Facilitate behaviour change by prompting environmental (physical and social) change

- A visible commitment to health and safety by management is important in determining the norms for health and safety at the individual level of the operative (Fleming & Lardner, 2002). The current research found that most operatives felt their respective organisations were committed to health and safety e.g. in terms of adequate PPE provision, supervision of apprentices, signs reminding operatives of risks associated with operating machines, and an 'open' culture (operatives felt supported for raising safety concerns). Managers also perceived themselves as committed to health and safety and were often approachable/ visible on the shop floor. However, commitment to non-defeating was not always evident to operatives. As managers had previous shop floor experience they were often understanding / appreciative of the reasons for defeating and would '*turn a blind eye*'. Such attitudes can be perceived as supporting the practice and undermines a company's avowed commitment to health and safety.

Consistent reinforcement of appropriate behaviour by management is more likely to ensure sustained change. Ways in which managers can get actively involved and visibly demonstrate their commitment could be explored. For example, taking part in committees/workgroups, attending training, giving immediate feedback on operatives behavior (e.g. actively discouraging defeating), having worker involvement objectives in their own performance appraisals.

- The current research found that it is difficult to detect when interlocks are defeated. This makes it difficult for managers/supervisors to enforce compliance. Strategies to aid detection e.g. audible/visible alarms could therefore be considered.

<u>Establish behaviours using rewards</u>

- A fair evaluation and reward system is needed to promote safe behaviour and discourage/ correct unsafe behaviour. An organisation's safety culture is reflected by the extent to which it possesses an established system for reinforcing safe behaviours (e.g. public praise/recognition by management/peers), as well as systems that discourage or punish unsafe behaviours (Reason, 1990). The current research found that the majority of organisations had formal disciplinary procedures in place to address incidents associated with the defeating of safety interlocks. There were variations however as to how these would be implemented. Often defeating would be dealt with informally. In many cases, defeating was accepted as 'routine' practice for certain tasks (e.g. maintenance and setting). There was a sense that defeating interlocks was 'punished' only when it happened outside of these activities.

  Reward and disciplinary systems should be formally documented, consistently applied, appropriate to the organisation and tasks and thoroughly explained and understood by all employees. Providing rewards such as financial incentives or public praise and recognition can help ensure that good work practices are continued long term. Recognising the importance of consistent and fair evaluation and reward systems is therefore important. Additionally, consideration could be given to the use of existing mediums for rewarding organisations for health and safety performance e.g. industry safety awards.

<u>Foster a positive behaviour related identity</u>

- Other people's behaviour plays an important role in determining the norm. Evidence shows that this can be leveraged; small numbers of key people can have a big impact on the behaviour of others (Gladwell, 2000). Focusing effort to create behaviour change within specific groups who will help promote wider change and foster a positive identity amongst operatives in the engineering industry could be helpful. The current research found that supervisors have a key role to play, often engaging in defeating themselves and are perceived by operatives to support the practice. Communication and training interventions targeting this group specifically e.g. recruiting supervisors as health and safety champions, who lead by example, model and enforce good practice could prove a useful strategy.

<u>Enhance social skills</u>

- In order to sustain change, and for an intervention to be widely adopted, it must be implemented and owned by workers themselves (Bell et al, 2011). Involving operatives in health and safety decisions will help ensure that risk controls are practical, problems are reported, and operatives have a genuine commitment to a positive safety culture, which they have helped to shape. Operatives are more likely to use machines appropriately if they have been actively involved in their selection. However the current research found a lack of formal worker involvement strategies and limited involvement by operatives in machine procurement decisions. SME engineering companies could be helped to implement / improve worker involvement in the context of CNC machines and interlocks and, health and safety in general. This could include helping operatives enhance social skills such as communication, giving and receiving feedback and assertiveness. Workshops could also be used to review worker involvement procedures.

5.3 RESEARCH CAVEATS

The key research caveat related to the sample used and that the findings of this small-scale qualitative research cannot be generalised to the larger population of SMEs in the UK engineering industry. Respondents were invited to take part in the research because of their experience in this specialist area, making the sample purposive as well as opportunistic. All of the organisations agreed to participate as a result of previous/existing contact with HSE (had been served improvement or enforcement notices). Part of the rationale for the sampling strategy was to ensure the research would be conducted on companies who had been found to be defeating interlocks. It was reasoned that such participants would be less likely to deny the practice than others not similarly served notices, (who may be more likely to tell HSE what they thought we wanted to hear i.e. that they never defeated interlocks).

The sample size was small. However, in qualitative research, exploring the range and nature of views, experiences and behaviours is more important than the extent to which they occur in the population of interest, which is the realm of quantitative inquiry. It is important to note that it was not possible to draw statistical inferences from this kind of sampling method since, with a purposive non-random sample, the number of people who participate is less important than the criteria used to select them. Theme saturation was reached within the data analysed (no new themes were emerging), which may be argued as offsetting the limitations of the small sample used. However it must be acknowledged that the range of themes produced may have increased further had a bigger sample been used.

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7. APPENDICES

7.1 APPENDIX 1- METHOD

7.1.1 Development of interview and focus group/group interview schedules/topic guides

Interview and focus group/group interview questions were developed in the form of schedules/topic guides. Preliminary fact finding research to inform development of the question sets also involved observation of CNC machines and guards/interlocks. The lead researcher and a team member visited the engineering unit at HSL to observe the relevant types of machinery and guarding devices, and the relevant types of tasks conducted by operatives.

HSL psychologists ensured that questions were open, not leading and elicited the correct information in relation to the objectives of the research. A semi-structured format provides a suitable balance between ensuring comparability across participants, and a scope for more in depth exploration of specific practices. Semi-structured interviews and focus groups allow for flexibility of response by participants and flexibility for the researcher (Breakwell 2000) to ensure that information is gathered to its 'exhaustion' whilst addressing the research questions (detailed in section). Semi structured schedules/topic guides:

- Enable more specific, in-depth information to be gathered than can usually be achieved in group interviews.
- Are much less constrained and more in-depth information can be obtained than through questionnaires.
- Encourages two-way communication and the development of relationships with key individuals in a community.
- Are administered in an atmosphere that makes respondents feel at ease.

Semi structured interviews also allow for 'unexpected' information to surface during the interview.

Furthermore, in order to be consistent with the approach taken to review the literature and quantitative data in phase 1, and to ensure a theoretical framework, the schedules/topic guides were based upon an established theoretical framework, the PRECEDE Model (Green, Kreuter, Deeds & Partridge, 1980). This model is an appropriate theoretical framework to adopt for this research, as it is capable of accommodating a disparate range of individual and organisational factors. Unlike traditional models of behaviour change, it goes beyond individual-level variables to consider important social-environmental factors and the context within which behaviour occurs (Sheehy & Chapman, 1987; Smith & Beringer, 1987; Dejoy, 1996). According to the model, three sets of diagnostic factors drive behaviour.

Predisposing factors are characteristics of the individual (e.g. knowledge, risk appraisal, beliefs) that facilitate or hinder the uptake of risk controls. **Enabling** factors refer to objective aspects of the environment/system that block or promote the uptake of risk controls. These include; skills, availability and functionality of appropriate machines and other equipment, work demands, visibility of operating field, policy and procedures, training, communication, current legislation/guidance, employee involvement, benefits and costs (e.g. time delay) associated with the use of risk controls. **Reinforcing** factors concern environmental features of systems that reward or punish compliance related behaviour (any reward or punishment that follows or is anticipated as a consequence of behaviour). These refer to e.g. the prevailing health and safety climate, observable management commitment to health and safety, prior experience of enforcement, production benefits, peer and employee attitudes/knowledge.

This model does not claim to have watertight reliability and validity for all possible occupational contexts. Rather, it provided a scientific framework for selecting important contributors to operative's behaviour in relation to the defeating of interlocks. Basing the questions upon this framework facilitated the identification and categorisation of potential influencing factors upon operative behaviour. This model was selected because it:

- Allows the decisions underpinning practices be examined.
- Is neutral, and not biased to a particular type of practice.
- Allows due consideration of organisational level and unit/individual level practices.

7.1.2 Sample

Strand 1: Interviews and Strand 2: Focus groups/group interviews

A purposive sampling strategy was used to obtain the interview and focus group/group interview participants. In qualitative research, exploring the range and nature of views, experiences and behaviours is important, more than the extent to which they occur in the population of interest (the realm of quantitative inquiry). Therefore, it is more practical to sample respondents for qualitative data capture purposively. Purposive sampling is the selection of participants who have particular characteristics, knowledge, or experience which will enable detailed exploration of the research objectives. It is important to note that it is not possible to draw statistical inferences from this sampling method since, with a purposive non-random sample, the number of participants is less important than the criteria used to select them.

The purposive sample was drawn from engineering organisations that have previously been served prohibition and/or improvement notices related to the failure to use interlocks/guarding appropriately. In order to obtain views and opinions from all levels within the organisation the sample was split into two key sub groups:

- Business owners/Directors/Business partners/Health and safety managers.

- Supervisors and Operatives (of CNC / manual machines with interlocks).

HSL identified suitable candidates to recruit using data taken from HSE's accident/incident and enforcement database (COIN). The help of HSE inspectors was also used to generate contacts within suitable organisations to take part. Small and medium sized enterprises (SME) were targeted rather than large organisations as large organisations typically subcontract this type of work to SMEs. There were 240 relevant organisations on the COIN list. Researchers worked their way through the list systematically from the start of the list down. Attempts at contact were made to 50 organisations. Of these 10 had invalid phone numbers, 26 stated no interest or asked for the researcher to ring back, 14 requested further information. Of these, however only 2 companies agreed to participate and were recruited. Due to the difficulty in recruitment, assistance from HSE inspectors was used. Four organisations were recruited via contacts supplied directly by HSE inspectors.

Such a sampling strategy could be argued as liable to selection bias (i.e. companies who have been exposed to HSE and may wish to secure a positive appraisal). However, this strategy was considered acceptable for this exploratory research and fits with the research aims and purposive sampling strategy (selecting participants with particular characteristics, knowledge and experience of the defeating of interlocks). In order to ensure that organisations did not feel coerced into participating organisations were recruited by HSL rather than HSE. HSL contacted organisations once the relevant HSE inspector had given clearance to approach and recruit. Participation was voluntary and participants were advised that they may withdraw consent at any time.

The intention following phase 1 had been for the three industries of engineering, plastics and woodworking to be included in the research. However, no suitable organisations were identified within the plastics and woodworking industry. The joint decision was therefore made between HSL, HSE and SSU to conduct the research in only the engineering industry.

The geographical distribution of organisations recruited ranged across the UK (Scotland, South West, Midlands, North East and North West of England).

Additionally, a one-to-one interview was conducted with a member of HSL's engineering unit This individual has extensive knowledge and experience of CNC machines (as a supervisor and operative) within industry and had been previously consulted when drafting the question set. The HSE customer and HSL research team were of the opinion that interviewing this individual would permit futher exploration of the research objectives.

7.1.3 Recruitment

Strand 1: Interviews and Strand 2: Focus groups/group interviews

Once potential participant organisations and contact details were obtained, HSL made initial contact with the organisation via telephone asking for their participation in a duty holder/management interview, and an operative/supervisor focus group/group discussion to discuss the key questions outlined in section 2.1. It was made clear that participation in this research was optional.

HSL made three attempts to contact the person responsible for health and safety (e.g. duty holder/employer/managers) at the organisation. Prior to making any contact the relevant HSE inspector was informed. The first attempt consisted of a telephone call detailing the background and purpose of the research and what their voluntary participation would require. This was followed up with a letter of invitation to agree participation, representing the second attempt at contact. If attempt one and two failed to secure recruitment a third and final attempt was made to contact potential recruits by telephone Following the third attempt, and if recruitment had failed it was assumed that the organisation did not wish to participate in the research and no further contact was made.

After agreeing to participate a suitable date to conduct the interview and focus group/group interview was scheduled. The person responsible for health and safety at the organisation was fully briefed on the purpose of the research, what taking part would involve and asked to nominate relevant operatives/supervisors within the organisation. An information sheet detailing the research and an attached consent form (see Appendix 2) was emailed to participants prior to the interview and focus group/group discussion. Duty holders were asked to complete the consent form and return this to the researchers via email or post.

It was emphasised to management that they should select operatives according to knowledge, experience and work practices relevant for this research. Furthermore, the information sheet provided duty holders/managers with a set of criteria/requirements for the types of supervisors and operatives needed to participate. These criteria were drawn up by HSL in consultation with the HSE technical customers and SSU. Additionally managers were reminded that consent to participate must be voluntary and supervisors/operatives must not be coerced in any way. As a safeguard, HSL researchers at the beginning of the interviews and focus groups reaffirmed consent and volunteers were given the opportunity to withdraw from the research at any time.

Within the organisations recruited, the number of participants for the focus group/group interview was deliberately kept flexible to accommodate staff availability and work demands on the day.

7.1.4 Data collection

Strand 1: Interviews and Strand 2: Focus groups/group interviews

Members of HSL's Human Sciences team collected data via interviews with management and focus groups/group interviews with supervisors/operatives. Interviews and focus groups were conducted to ascertain participant's perceptions and opinions of the reasons why operatives defeat or are motivated to defeat interlocks and guarding devices from an organisational viewpoint. The interviews and focus groups followed a semi-structured set of questions (see Appendix 4).

The project leader gave instructions to the team in the use of the question set to ensure that the questions were interpreted in the same way by each researcher and any issues of ambiguity and or common misunderstandings could be addressed. It was important that the interviewer was well versed as to the nature of the research so as to ensure the participant's responses address the question set. This helped ensure reliability across the research. Interviews and focus groups lasted between 50 and 70 minutes, were digitally recorded and transcribed verbatim.

During the interviews/focus groups, the HSL researcher facilitating the session used the semi-structured topic guide, and recorded any non-verbal behaviour or useful analytical comments. Facilitators posed a number of questions and encouraged participants to express their experiences and views freely. It should be noted that the number of focus group/group interview participants was dependent on business size and demands and the number of participants willing to participate. Consequently, due to the disparate size of the organisations recruited, focus groups were conducted with between two to six participants.

At the start of the interviews and focus groups, details about the purpose of the research and how data would be used was given to participants. Verbal consent was obtained from all participants to digitally record the session and make written notes.

Prior written consent had been obtained from Managers/duty holders to conduct the research within their organisation. This consent was reaffirmed verbally at the start of the management interview. Within the focus groups/group discussions no written consent was taken. Therefore sufficient background information was given prior to commencing the focus group to allow them to give their informed consent. All participants were told that their participation was voluntary, they could change their mind about taking part at any point or they could choose not to answer particular questions.

7.2 APPENDIX 2 – INFORMATION SHEET/CONSENT FORM

HEALTH & SAFETY LABORATORY

Harpur Hill, Buxton
Derbyshire, SK17 9JN
Telephone +44 (0)1298 21800
Facsimile +44 (0)1298 218590

[Add Recipient's Name & Address]

[Add Date]

Dear (add recipient's name),

Following on from our recent telephone conversation, I am writing to thank you for agreeing to take part in the research that HSL are conducting in relation to the defeat of interlocks on CNC machines. This letter is to provide you with more information about the research project and obtain your formal consent.

Please feel free to contact me at any point with any further questions that you may have or if you no longer wish to participate in the research.

Thank you again for helping us with this valuable research. Your views and opinions are valuable to HSL and HSE.

Yours sincerely,

Jane Hopkinson,
Work Psychology Section,
Health and Safety Laboratory,
Harpur Hill,
Buxton,
Derbyshire.
SK17 9JN.

Enc.

Direct tel: +44 (0)1298 218708
Direct fax: +44 (0)1298 218571
Email: jane.hopkinson@hsl.gov.uk

Interlocking research project

Who is conducting this research?
The Health and Safety Executive (HSE) have commissioned Health and Safety Laboratory (HSL) Work Psychologists to undertake this research. HSL undertakes research on behalf of HSE.

What is the purpose of this research?
The HSE has commissioned the HSL to identify the reasons why operatives defeat or by-pass machinery guarding. In particular we are interested in the safety interlocks provided to a variety of Computer Numerical Control (CNC) machines. The aim of the project is to understand the issues in relation to the type of machines, actual practice and associated incident/accidents.

This research will enable HSE to provide better guidance to industry and HSE inspectors alike. In turn, this will help to provide improvements in compliance and possibly improvement in machine design as it is anticipated this research may have suggestions for how operatives interface with machines.

What does the research involve if I agree to take part?
You have indicated your interest in participating in this research. Your participation will require an HSL researcher to visit your premises at the date/time agreed to conduct two separate face-to-face interviews with yourself or the health and safety manager, and with a supervisor. Each interview will last approximately 45 minutes. We will also conduct a group discussion with operatives (6-8 individuals if possible). This discussion will last approximately 1 hour. You should select supervisors and operatives according to relevant knowledge, experience and work practices for this research i.e. supervisors and operatives need to be those who regularly use CNC machines or supervise operators using these machines. **Their participation must be voluntary and you must not coerce them in any way to participate.** If you and the other participants in your organisation are happy for us to do so, we would like to record the interview/group discussion so that we have an accurate record.

Do I have to take part?
Taking part in this research is entirely voluntary. If you do decide that your organisation will take part, please complete the attached consent form agreeing that HSL hold the information you provide for research purposes only. You and the other participants may withdraw from the research at any time without giving a reason. Also, feel free to ask the research team any questions if anything is unclear. If, for whatever reason, you are not happy to answer any specific questions, please make this known to the researcher who will be happy to leave that topic and move to the next one.

Will the information I provide be treated in confidence?
Under no circumstances will personally identifiable information be reported in research reports/articles, and you can be assured that anonymity will be upheld. However, within this consent form we do ask whether you would prefer that your organisation's name is kept anonymous within the report and presentations arising from this research, or acknowledged for your contribution. If you prefer to remain anonymous, we will provide your organisation with a pseudonym (e.g. company A, company B etc) by which it will be referred to in the reports findings.

HSL's data management systems abide by the requirements of the Data Protection Act. Information you share with us will be held at HSL on a secure network or in a locked cabinet and will be only used by researchers involved in the project for the purposes of this research. All data will be destroyed ten years after the research is completed in line with the Data Protection Act.

Who else is involved in the research?
We are asking five other small to medium sized companies to participate in this study.

What do I do next?
If you are happy to take part in this research please read through the **consent form** below and return either as an attachment via email or by post to the address below. Consent from any other interview/discussion group participants will be obtained verbally at the time of conducting the research. If you are returning via email please indicate consent by typing the name on the signature line. If you have any other questions or would like any further clarification, please contact:

Mrs. Jane Hopkinson
Health and Safety Laboratory
Harpur Hill
Buxton, Derbyshire
SK17 9JN
Tel: 01298 218708 (jane.hopkinson@hsl.gov.uk)

Please read and initial each statement below and completed the top part of the box at the end.

I confirm that I have read and understand the Information Sheet dated ……………… for the above research, have had the opportunity to ask questions, and understand what I am expected to do as a volunteer.

(Write or type initial here)…………………………

I understand that my participation is voluntary and that I may withdraw at any time, without giving any reason for doing so.

(Write or type initial here)…………………………

I am happy for written notes to be made of my interview / I am happy for the interview to be audio recorded.

(Write or type initial here)…………………………

I understand that any recordings or written records of my contribution will only be used for the purposes of this research, and will not be stored beyond the duration of this research.

(Write or type initial here)…………………………

I would prefer that my company's name is / is not (delete as appropriate) acknowledged in the report findings and presentations.

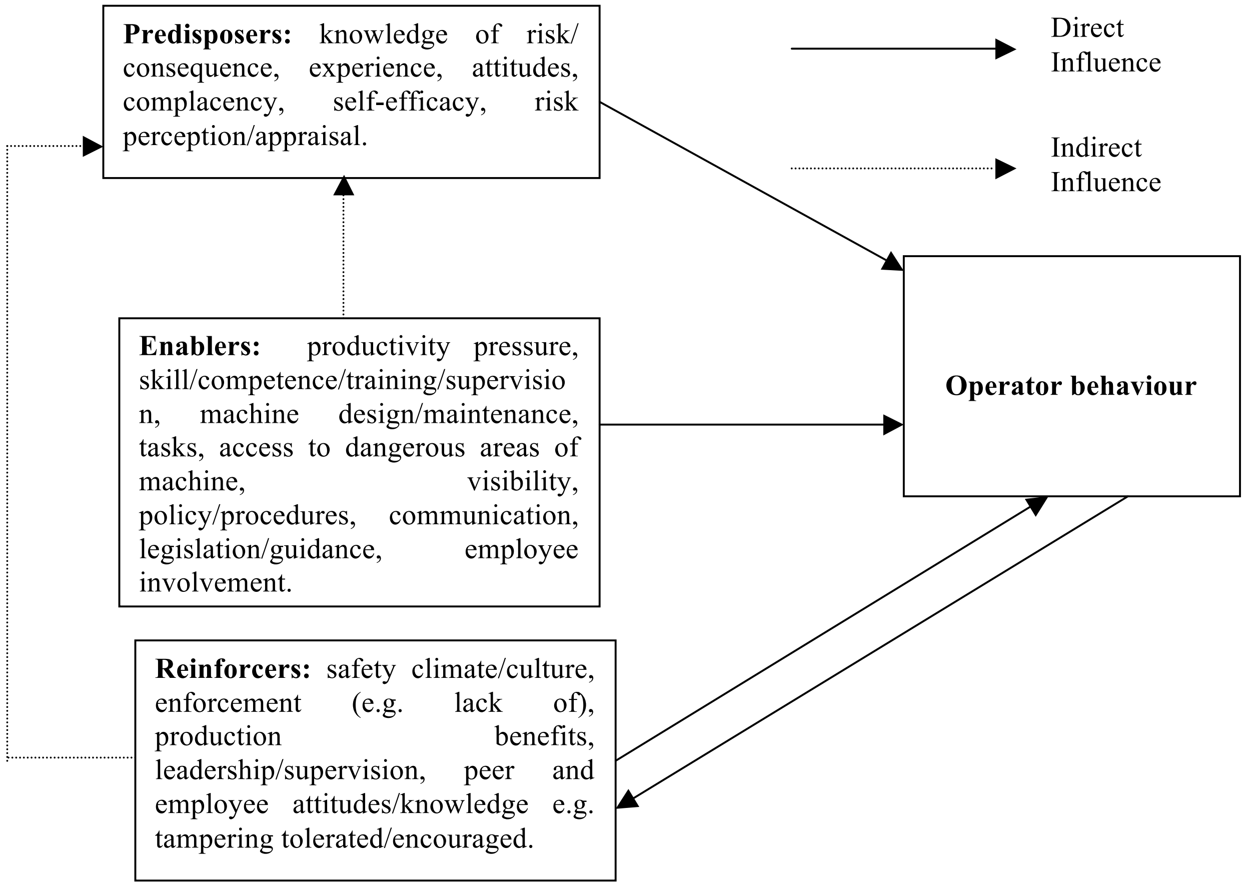
(Write or type initial here)…………………………

I understand the reason for this research and agree to participate.

(Write or type initial here)…………………………

Your name……………………………………………………………………………… Date……………………………………………………………………………………… Signature………………………………………………………………………………… (Please type your name if returning via email)
Name of Researcher…………………………………………………………………… Date……………………………………………………………………………………… Signature…………………………………………………………………………………

7.3 APPENDIX 3 - PRECEDE MODEL POPULATED WITH FINDINGS FROM PHASE 1 RESEARCH



7.4 APPENDIX 4 – QUESTION SETS

7.4.1 Interview Schedule - Managers

- **Who we are and why here** - State name. HSL are conducting this focus group on behalf of HSE.
- **Background** – HSL have been commissioned by HSE to carry out research exploring the reasons, in terms of human factors, why operatives defeat or are motivated to defeat or by-pass the interlocks on CNC machines. Tampering has been identified as a common occurrence by previous research.
- **Aim** - The aim of this interview is to explore in more detail management opinions as to why operatives are defeating the interlocks. The information that you provide today will be completely confidential. It will help HSE to consider how they could provide better guidance/support to help reduce the need to defeat interlocks.
- **Plan for the session** –
    - Should take between 30 - 45 minutes to one hour.
    - Open questions related specifically to the aims of the project, namely:
        - Extent to which interlocks are defeated.
        - Why interlocks are defeated.
        - What can be done to improve the situation?
    - There are no right/wrong answers everyone's view is of interest. We would like you to be frank and given your honest views and opinions.
- **Explain how we gather your views** – explain that we would prefer if the interview is audio recorded – obtain consent. Recording ensures views are captured and avoids the use of a note taker.
- **What we will do with the data**
    - Data will be transcribed by an external company and is done to ensure all of the views are captured completely and accurately. All transcripts will be anonymised to remove any contact names.
    - Prepare reports that do not identify individual participants or organisations.
    - Data will be kept secure – both on site and computers.
- **Any questions?**

Note: These questions serve as a guide for items to inquire and probe among participants in the focus groups. The intention is not to ask verbatim each specific question. Rather, the major items in each section are investigated, and probed for additional details based on participants' responses to the major questions.

Introduction

1. Name, role – typical tasks undertaken on a daily basis.

2. Length of experience as manager? Prompt: Previous experience e.g. operator/supervisor? How much 'hands on' experience themselves of using CNC machines? Did you ever experience defeating interlocks when operating machines e.g. other people doing it etc?

Extent of the problem

3. What types of CNC machines / guards / interlocks do your operatives work with? What activities / tasks do they carry out with these CNC machines? Prompt: types of production activity, maintenance, etc.

4. In your opinion/experience what, if any, activities are more likely to lead to the defeating of interlocks e.g. maintenance, clearing jams? What is the reason for this do you think?

Predisposing factors

(Focus in this section is on assessing personal susceptibility of risk, understanding of the true risk and consequences as well as self-efficacy).

5. Do you think it is ever 'safe' to defeat an interlock? Prompt: When, why, in what circumstance?

6. Do you perceive any risks / consequences (to operatives and/or the organisation) associated with defeating the interlocks? What do you think could go wrong if an operative defeated interlocks? What do you think all possible consequences of defeating an interlock are? Prompt: serious injury / death, finger laceration, amputation, minor injury, risk of enforcement action, legal and operational consequences of tampering.

7. Is there more/less risk for CNC or manual machines? Reason for answer?

8. What do you base your knowledge of the risk on (sources of your knowledge)? Prompt: Training, previous experience, manufacturer guidance, HSE? Do you think your supervisors/operatives have a full understanding of the risk? What do you think they base their knowledge on? E.g. peers, previous employment, your attitudes and behaviours?

9. How do you communicate health and safety (in general and machine safety) issues to your operatives? How do you ensure/check the methods used are effective?

10. Do you think more could/should be done by HSE to raise awareness of the risks and consequences of defeating interlocks? If so, how?

Enabling factors

11. What is your opinion of the current controls (safeguards, interlocks, procedures) you provide to protect your operatives safety? Prompt: Are they practical and necessary? Are they used appropriately and effectively? What in your opinion is the main purpose of interlocks e.g. to provide protection from slurry spray, to prevent injury?

12. Do you feel you have the necessary knowledge/information on the functionality of CNC machines to allow you to manage your operatives? Prompt: E.g. are you familiar with all the operating modes on your machines e.g. setting mode? Where do you get this information? Do you consult the machine manuals? Have you had training, adequate guidance?

13. Do you believe that your operators are equipped to operate CNC machine effectively? How do you ensure this? Prompts: adequately supervised, what training do you provide for CNC machines and health and safety? E.g. is it only generic machine operating training or do you provide machine specific training and familiarisation (if moving from machine to machine). Do you provide training on how to clear blockages/jams, operating procedures in emergency, refresher training? How do you assess competence? Do you think the training you provide could be improved? If so, how?

14. In your opinion what are some of the reasons / influences that could cause your operatives to defeat, or be motivated to defeat, an interlock on a CNC machine? *NB: if they have*

denied defeating in this organisation ask this as a hypothetical question. Prompt: Probe responses given initially and also explore the following if appropriate: deadlines / productivity demands, time delay associated with the use of safety devices, perceived stress/job pressure, lack of adequate supervision / training, ergonomic issues such as poor visibility and adequacy of lighting (how often do they replace viewing panels), previous experience of working with unguarded manual machines, routine violation - everyone doing it, machine jams/stops working / troubleshooting, maintenance activities, awkward safeguards making work more difficult or time consuming, when checking the quality of work, because machines can be operated easily with interlocks defeated. Do you use probes e.g. when setting machines? Does using probes require you to defeat interlocks?

15. What tools techniques could operatives use to defeat interlocks, how long does it take? Prompt: Do manufacturers provide tools to do this e.g. Allan keys? How do operatives learn about and access these defeating tools/techniques?

16. Where do you access standards/guidance and procedures for use of CNC machines? Are they easy to understand and interpret? Prompt: are they a help or hindrance? Could they be improved? Are they practical and up to date? How often do you review procedures? Would guidance targeted at certain audience groups be useful i.e. operatives, supervisors and managers?

17. How do you consult/involve your supervisors and operatives in health and safety? Prompt: Use of safety reps? Choice of machines, developing procedures, risk assessments, best way of working etc? How do you ensure your supervisors and workers know you value their opinion? Can consultation/worker involvement reduce the incidence of defeating interlocks or identify ways to defeat interlocks in a safe way?

18. Where do you obtain your machines from Prompt: e.g. second hand, via dealers, auctions, new from manufacturer/supplier? What is your main motivation for choosing a machine? Prompt: suitability for task, safety, price?

Reinforcing factors

19. Do you perceive any benefits associated with defeating the interlocks on CNC machines? If so, what? Prompt: able to work faster, improve visibility of job, deal with faults more efficiently? Do you think your supervisors/operatives perceive benefits? If so, what? Do you praise/recognise your operatives for working safely?

20. How do you demonstrate your commitment to health and safety? Prompt: do you enforce procedures? How do you make sure supervisors encourage safe behaviour? Do you encourage or discourage the defeating of interlocks? What messages do you think you send out, if any, regarding the importance of safety vs. productivity?

21. How do you deal with incidents of defeating interlocks? Prompt: What happens if someone is caught defeating? Do you investigate/reprimand? How?

22. How easy is it for you/your supervisors to detect if interlocks are defeated? Prompt: Can anything be done to make detection easier e.g. visual and functional checks to ensure no tampering, inspection checklists.

23. What do you think the consequences would be if machines were operated at all times with the CNC interlocks in place and working as they should be? Would there be any “costs” or downsides to doing this?

Suggestions for improvements:

24. Is there anything that you think could be done to promote safer ways of working when operating CNC machines?
    - Prompt: Better signage, communication between maintenance staff and operatives, use of risk assessments, suggested manufacturer maintenance.
    - Prompt: Could machine design be improved? If so, what changes would you make? E.g. use of fixed safeguards, installation of interlocks between safeguards and equipment, sensors to signal when machine is used without safeguard, designers aware of safeguarding issues, making safeguards easy to see through and reach over, making guards easy to replace.
    - Prompt: In your opinion is there anything more that could be done to support organisations in reducing the incidence of defeating interlocks on CNC machines? What? Who by? E.g. guidance, enforcement, etc.

Close

Is there anything else you would like to add? Thank participants for their time. Recap on what will happen with the data. [Transcribed, put together with others' responses, report made avail to public, not identified]. Provide contact details if they need anything further.

7.4.2 Focus group/group interview schedule – Supervisors/operatives

- **Who we are and why here -** State name. Explain HSL are conducting this focus group on behalf of HSE.
- **Background** – HSL have been commissioned by HSE to carry out research exploring the reasons why operatives defeat or are motivated to defeat the interlocks on CNC machines. Tampering has been identified as a common occurrence by previous research.
- **Aim -** The aim of this focus group is to explore in more detail why operatives are defeating interlocks. Information that you provide today will be completely confidential. It will help HSE to consider how they could provide better guidance/support to help reduce the need to defeat interlocks.
- **Plan for the session –**
    - Should take between one hour to one hour and a half.
    - Open questions related specifically to the aims of the project, namely:
        - Extent to which interlocks are defeated.
        - Why interlocks are defeated.
        - What can be done to improve the situation?
    - There are no right/wrong answers everyone's view is of interest. It is an open discussion and we would like you to be frank and given your honest opinion. The aim is to hear as many different thoughts as possible. There are likely to be different views/experiences but people should feel free to say what they think.
- **Explain how we gather your views** – explain that we would like the focus group to be audio recorded – obtain consent. Recording is used to ensure all views are captured and avoid the use of a note taker.
- **What we will do with the data**
    - Data will be transcribed by an external company and is done to ensure all of the views are captured completely and accurately. All transcripts will be anonymised to remove any contact names.
    - Prepare reports that do not identify individual participants.
    - Data will be kept secure – both on site and computers.
- **Any questions?**

Note: The questions that follow serve as a guide for items to inquire and probe among participants in the focus groups. The intention is not to ask verbatim each specific question. Rather, major items in each section will be investigated, and probed for additional details based on participants' responses to the major questions.

Introduction

1. Name, role – typical tasks undertaken on a daily basis?

2. Length of experience working on CNC machines?

Extent of the problem

3. What types of CNC machines/ guards / interlocks do you all work with on a regular basis? What activities / tasks do you carry out with these CNC machines? Prompt: types of production activities, maintenance, etc.

4. In your opinion what, if any, activities are more likely to lead to the defeating of interlocks e.g. maintenance, clearing jams? What is the reason for this do you think?

Predisposing factors (Focus in this section is on assessing personal susceptibility of risk, understanding of the true risk and consequences as well as self-efficacy).

5. In your opinion is it ever 'safe' to defeat an interlock? When, why?

6. Do you perceive any risks / consequences (to you and/or the organisation) associated with defeating the interlocks? What do you think could go wrong if an operator defeated interlocks? What do you think all the possible consequences of defeating an interlock are? Prompt: serious injury / death, finger laceration, amputation, minor injury, risk of enforcement action, legal and operational consequences of tampering.

7. Is there more/less risk for CNC or manual machines? Reason for answer?

8. What do you base your knowledge of the risk on? What are the sources of your knowledge? How would you consider your risk compared with your peers e.g. more or less? Why? Prompt: Training, previous experience, peers opinions/experience, supervisor/management behaviours.

9. Generally, how health and safety 'aware' do you think this organisation is? What makes you think this?

10. How is health and safety communicated to you? Prompt: In general? In relation to machine safety? Are the methods used effective in terms of getting the H & S message across? Could anything be done to improve communication in relation to machine safety?

Enabling factors

11. What is your opinion of the current controls (safeguards, interlocks, procedures) in place to protect your safety? Prompt: Do they work? Are they appropriate and necessary? What is the main purpose of interlocks Prompt: e.g. to provide protection from slurry spray/flying swarf, to protect safety?

12. Do you believe you fully understand the functionality of the CNC machines you operate? Prompt: E.g. are you familiar with all the operating modes on your machines e.g. setting mode? Where do you get this information? Peers, supervisors, training? Do you consult the machine manuals? Are you adequately supervised? Do you get only generic machine operating training or machine specific training and familiarisation (if moving from machine to machine)? Do you know how to clear blockages/jams, operating procedures in an emergency? Do you get refresher training? Is it beneficial? Could training be improved? If so, how?

13. In your opinion what are some of the reasons / influences that could cause an operative to defeat, or be motivated to defeat, an interlock on a CNC machine? NB: if they have denied defeating in this organisation ask this as a hypothetical question. Probe responses given initially and also explore the following if appropriate: Prompts: deadlines / productivity demands, time delay associated with the use of safety devices, old equipment, lack of on site staff with specialised knowledge of the machines, lack of peer and manager support, when under stress/job pressure, lack of adequate supervision / training, ergonomic issues such as poor visibility and adequacy of lighting, previous experience of working with unguarded manual machines, routine violation - everyone doing it, machine jams/stops working / troubleshooting, or because of maintenance activities, awkward safeguards making work more difficult or time consuming, when checking the quality of work, because machines can be operated easily with interlocks defeated, poor accessibility and / or functionality of machines. Do you use probes e.g. when setting machines? Does using probes require you to defeat interlocks?

14. How do operatives defeat interlocks and how long does it take? Prompts: Use particular tools/techniques e.g. Allan keys. How do they learn about and access these defeating tools/techniques? Is it easy to do?

15. How easy are standards/guidance and procedures for use of CNC machines to understand and interpret? Why? Prompt: are they a help or hindrance? Could they be improved? Are they practical and up to date? Are procedures reviewed? How often? Would guidance targeted at certain audience groups be useful i.e. operatives, supervisors and managers?

16. Do you feel that management involve you in health and safety decision-making? Prompt: Are you involved in the choice of machines, best ways of working, developing procedures/risk assessments, management seek your opinions, etc? Do you think you should be involved in decision-making? What improvements to worker involvement would you suggest?

17. If you had to operate your machines at all times with functioning interlocks in place and working as they should be, are there certain aspects of your work that would be more difficult/impossible?

Reinforcing factors

18. Do you perceive there to be any benefits associated with defeating the interlocks on CNC machines? If so, what? Prompt: work faster, improve visibility of job, deal with faults more efficiently, praise from managers at getting job done quicker? Are you praised/recognised for working safely?

19. To what extent do you feel that this organisation prioritises / is committed to health and safety? How is this demonstrated? Prompt: are procedures enforced? Is safe behaviour encouraged? If so, how, e.g. supervisors/managers behaviours? Do management walk by? Productivity vs. health and safety? Why and what makes you think this?

20. How are incidents of defeating interlocks currently controlled / dealt with by supervisors/management? Prompt: What happens if someone is caught defeating one? Is there an investigation, reprimand? Is there peer disapproval? In your opinion is tampering tolerated in this organisation/industry?

21. How easy is it for managers/supervisors to detect if an interlock has been defeated? Prompt: Can it be reinstated quickly/easily making detection difficult? Can detection be made easier e.g. visual and functional checks to ensure no tampering, inspection checklists.

Suggestions for improvements:

22. Is there anything that you think could be done to promote safer ways of working when operating CNC machines?
    - Prompt: Better signage, communication between maintenance staff and operatives, use of risk assessments, suggested manufacturer maintenance.
    - Prompt: Could machine design be improved to reduce the number of problems / injuries experienced? If so, what? E.g. use of fixed safeguards, installation of interlocks between safeguards and equipment, sensors to signal when machine is used without safeguard, designers aware of safeguarding issues, making safeguards easy to see through and reach over, making guards easy to replace.
    - Prompt: In your opinion is there anything more that could be done to support organisations in reducing the incidence of defeating interlocks on CNC machines? What? Who by? E.g. guidance, enforcement, etc.

- **Close**

Is there anything else anyone would like to add? Thank all participants for their time. Recap on what will happen with the data. [Transcribed, put together with others' responses, report made avail to public, not identified]. Provide contact details if they need anything further.

7.5 APPENDIX 5 – ANALYSIS PROCEDURE

Strand 1: Interviews and Strand 2: Focus groups/group interviews

Data collected in the semi-structured interviews and focus groups was analysed thematically using a framework analysis (Ritchie and Lewis, 2003) approach advocated by the National Centre for Social Research (NatCen, Pope et al, 2006). Thematic analysis enabled the researchers to gain an in depth understanding of participants' experiences and practices. Throughout the data analysis, reliability was assured by having regular team meetings, adopting a prescriptive procedure to mitigate any inconsistencies between researchers and having two researchers collaboratively develop the themes and typologies to ensure consistency in interpretation. Three stages of framework analysis were conducted. These are detailed below.

Data Management stage

- **Familiarisation:** Transcripts were read through so that researchers were familiar with the data, research questions and objectives.

- **Development of an analytical / conceptual framework:** The lead researcher used a Microsoft Excel spreadsheet to develop an initial analytical framework based upon the question set.

- **Identifying initial concepts / categories:** The research team collectively decided on appropriate categories and concepts for the framework based on their knowledge of the data (from previous stages of the project), research questions and research objectives. At this stage, the analysis was grounded in the data and therefore stayed close to the language and terms used in the data set.

- **Summarising transcript / synthesising data:** Members of the HSL research team entered each case into the framework by summarising the raw data. Analytical comments (i.e. researchers' own learning's and reflections) were included to better enable researchers to provide an accurate reflection of the interview/focus group. Direct comments from the transcript were tagged by line number. This ensured that other members of the team could check the analysis and thus ensured consistency. Furthermore, for the purpose of consistency all researchers were asked to summarise data which related to the PRECEDE Model (Green, Kreuter, Deeds & Partridge, 1980), upon which the question sets had been based, according to the criteria detailed in Box 3 below. Team meetings were held to ensure consistency of approach between the researchers. These were held at the beginning of the process, and a suitable timeframe during the analysis (after 3 cases had been entered) and at the end to check consistency in how the data was entered.

Predisposing - characteristics of the individual that help or hinder the uptake of risk controls: e.g. knowledge, beliefs, attitudes, values, age and experience, complacency/boredom, self-efficacy, risk perception etc

Enabling - objective aspects of the environment/system that block or promote the uptake of controls: e.g. skills/competence, availability, accessibility and functionality of appropriate machines and other equipment, tasks, work demands/time, visibility of operating field, policy and procedures, training, communication, current legislation/guidance, employee involvement, investment in controls, barriers and costs (e.g. time delay) associated with the use of risk controls.

Reinforcing - any reward or punishment that follows/is anticipated as a consequence of behaviour: e.g. safety climate/culture, organisational climate/culture, prior experience of enforcement, production benefits, leadership/supervision, peer and employee attitudes/knowledge, feedback, social approval or disapproval.

N.B: Whilst it is acknowledged that some of these categories may cross over themes. Researchers were asked to adhere to the above lists and to document reasons for any divergence.

Box 3. Criteria to identify Predisposing, Enabling and Reinforcing Themes

- **Testing the framework:** Once three transcripts had been entered into the framework the HSL research team compared/agreed/refined the categories.

Descriptive stage

- **Identifying elements and dimensions:** the concepts / categories identified in the data management stage were divided up between two HSL researchers for further analysis. From the transcript summary, elements / dimensions were detected. After each element / dimension the participants' individual case number was noted to link it to the original data. The HSL researchers discussed decisions made regarding the inclusion of elements / dimensions to ensure consistency of approach.

- **Categorisation:** For each concept / category, the elements / dimensions identified were re-ordered into broad overarching themes and then, if considered necessary re-ordered into more refined sub-themes.

Explanatory stage

- **Establishing Typologies:** A process of classification was used to develop typologies by combining two different dimensions from the data set. The only typology to emerge from the data (based upon the research objective of ensuring all levels of the organisation are explored) was a typology combining the dimensions of (i) Manager/duty holder (ii) Supervisor/operative. Each typology was independent (i.e. an individual case was only categorised in to one typology or 'group'), and all individuals were assigned to a typology.

- **Developing explanations**: Researchers then worked through the charted data in detail, drawing out the range of experiences and views (according to typology), identifying similarities and differences, developing and testing hypotheses, and interrogating the data to seek and explain associations, emergent patterns and findings. Finding associations involved the researchers iteratively going backwards and forwards within the data set looking for links or connections between the refined sub-themes developed in the descriptive stage and the typologies. In this way the typologies divided up the issue being researched and could show how certain views or experiences exist within different groups in the study population. This helped explain similarities/differences between data and improved understanding.

8. ANNEX REPORT

Contains the Literature Review, Quantitative and Qualitative analysis relating to the project:

Identifying the human factors associated with the defeating of interlocks on Computer Numerical Control (CNC) machines

PH05422

KEY MESSAGES

This report summarises the findings from the first phase of ongoing research to identify the reasons why operatives defeat interlocks (a switch or other device that prevents activation of a piece of equipment when a protective door is open or some other hazard exist) on Computer Numerical Control (CNC) machines and to obtain an understanding of the extent of this behaviour across industry.

There is little research evidence available that directly examines operative behaviour regarding the defeating of interlocks on CNC machines, the extent of this problem and the factors that influence such behaviour. Therefore, no definitive conclusions can be drawn from this phase for CNC machines. Instead, inferences were drawn from existing literature and analysis of secondary qualitative data to inform key implications about the areas that should be explored further in the next phase of this research (interviews with managers and supervisors and focus groups with operatives). It must be acknowledged that these inferences are on the basis of evidence in relation to injuries from unguarded machinery in general, which **may** include CNC machines. It was not possible to identify injuries specifically in relation to CNC machines.

EXTENT OF THE PROBLEM

The findings of the current research imply that:

- Defeating interlocks is widespread across industry and involves a variety of machine types and safety devices. This supports further research to explore the reasons behind this behaviour in the engineering, plastics and woodworking industries.

- There appears to be cross-cutting aspects to non-compliant behaviour in these industries; further research may help to identify industry-specific influences.

- Production, troubleshooting and maintenance activities are commonly associated with the defeating of safety devices, implying that the prioritisation of productivity over safety is an important influence upon behaviour. The next phase of this research should seek to explore the reasons why these activities appear to be more susceptible to the defeating of interlocks.

- The severity of consequences of defeating interlocks ranges from minor injury to fatality. It is reasonable to infer that such variety of consequence may bias risk perception/appraisal processes; operatives may fail to appreciate the full severity of consequences. It is essential therefore for ongoing work to explore risk appraisal/perception processes and influences upon them.

FACTORS INFLUENCING OPERATIVE BEHAVIOUR

- Little research to date has examined the psychological, social, organisational and environmental influences relating to operative behaviour and the defeat of interlocks on CNC machines.

- The current research suggests a number of influences on operative behaviour. These may be categorised as 3 types of factors:
    - Predisposing: characteristics of the individual that motivate behaviour e.g. risk perception, knowledge.
    - Enabling: features of the environment/system that block or promote the uptake of controls e.g. machine design, policies and procedures.

    - Reinforcing: any reward or punishment that follows or is anticipated as a consequence of behaviour e.g. production benefits from defeating interlocks (reward), enforcement and disciplinary action (punishment).

- The findings of this literature review and analysis of secondary qualitative data imply that all three factors are relevant to understanding operative behaviour. None of these should be overlooked if a thorough understanding of the influences on operative behaviour is to follow. As such, questions addressing the potential influence of each of the factors should be incorporated into the research tools (interview and focus group schedules).

IMPLICATIONS FOR ONGOING RESEARCH

The research tools should explore whether certain factors play a more prominent role in influencing behaviour in machine guarding compared with general health and safety management, plus identifying and exploring any new factors. The current findings imply that the proposed methodology for the next phase of the research (management/supervisor interviews and operative focus groups) is appropriate to provide novel insights into the specific knowledge, attitudes, values, beliefs and perceptions that operatives hold about the use of CNC machines and interlocks. It would also show how these interact with social/environmental influences to result in non-compliant behaviour (defeating/attempts to defeat interlocks). Finally, the current literature implies a number of possible solutions to the problem of defeating machine safety guards. Ongoing work should examine managers, supervisors and operatives' views on the feasibility and practicality of these suggestions specifically for interlocks and CNC machines, as well as seeking to obtain new suggestions for pragmatic and cost-effective solutions to this issue.

EXECUTIVE SUMMARY

BACKGROUND

The Health and Safety Laboratory (HSL) has been commissioned by HSE to carry out research to identify why operatives in engineering, plastics and woodworking premises defeat, or are motivated to defeat, or by-pass the safety interlocks provided to a variety of Computer Numerical Control (CNC) machines.

The defeating of interlocks on CNC, and other (manual) machines has been identified by HSE as a common problem in small and medium sized enterprises (SMEs) and attracts a significant level of enforcement action[26]. Current understanding suggests that despite enforcement action, operatives may continue to defeat interlocks. HSE's experience indicates that the practices often repeat over time within the same organisations and within similar industries. A better understanding of operative behaviour regarding the defeating of interlocks will be gained from this research to help HSE provide better guidance to its inspectors and industry. In turn, this should help to improve compliance behaviour and possibly initiate improvements in machinery design.

AIMS AND OBJECTIVES

The overall aim of this research is to identify the reasons, in terms of human factors, why operatives defeat, or are motivated to defeat, or by-pass the safety interlocks provided to a variety of CNC machines. A further aim is to determine the extent of the problem of defeating interlocks on CNC machines. This report represents the first deliverable of the broader research project. It provides an initial understanding of the nature and extent of the problem of defeating interlocks on CNC machines based on the available literature[27] and analysis of secondary qualitative data (accident/incident and enforcement data (COIN) and RIDDOR (Reporting of Injuries, Diseases and Dangerous Occurrences Regulations) reports)[28]. This covers factors likely to influence operatives' behaviour and forms the basis of suggestions about areas that should be explored in the next phase of this research.

KEY FINDINGS

Extent of the problem

The findings of this phase can only point to areas for further exploration in phase 2 as there was a lack of literature specifically about the extent of the problem of defeating interlocks on CNC machines. No literature was identified relating to the United Kingdom (UK), however literature did discuss the extent of the problem across industries within the USA and Europe. Much of the literature discussed machine safety in general and was not specific to any industry. Where an industry was specified, the majority of papers related to metal working/engineering industries, however literature was identified as relevant for other industries e.g. woodworking.

Despite these limitations, the literature review has provided valuable insights on the extent and prevalence of safety device manipulation. The literature suggests that bypassing safety devices

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[26] *It is important to note that although there is a high level of enforcement there is no evidence that this behaviour results in a high level of injuries*

[27] Wider literature in relation to unguarded machinery only as there is a dearth of evidence specifically in relation to CNC interlock machines.

[28] *A separate piece of work was carried out by HSE CSEAD to quantitatively assess the extent of the problem.*

is a widespread phenomenon across industry and machine type, with potentially serious consequences. Protective devices identified as commonly being tampered with included movable separating devices and mechanical, non-moving separating protective devices. However, no further explanation of these types of devices was given and it must be acknowledged that this could relate to non-CNC machines. Tampering activities included removing separated activators, and bypassing or dismantling switches. Tampering activities were reported as frequently observed during automatic and setting up modes, programming and re-adjusting modes. Troubleshooting and maintenance were also identified as activities associated with the manipulation of safeguards. The literature suggests that tampering behaviour is tolerated in many organisations. However, it was noted that accidents and near misses could not be solely attributed to tampering with safety devices. As a result, it is not possible to determine the prevalence of 'defeating behaviours' over other types of behaviours in causing the incidents from the literature.

The secondary qualitative data represented incidents/accidents that occurred across the UK (all Field Operations Directorate regions represented) in a broad range of industries. The data suggests there are common issues spanning industry. The types of injury sustained showed a broad variation ranging from fatality to fractures, amputations, lacerations and contusion. The majority of injured parties were engaged in production-related tasks, although incidents also occurred during maintenance/repair work. A variety of machines were reported in the data, with no one type of machine identified as most prevalent.

Factors influencing operative behaviour

The current literature review and qualitative analysis of secondary data identified a number of factors likely to influence operative behaviour regarding the defeating of safety devices/interlocks on a variety of machines. These have been categorised into three overarching factors: Predisposing; Enabling; and Reinforcing.

Predisposing factors are characteristics of the individual that help or hinder the uptake of risk controls. It was possible to identify several important predisposing factors that may influence the defeating of safety devices/interlocks from the literature and secondary data. These included awareness of personal susceptibility to risk and a lack of understanding of the 'true risk', i.e. the possible severity of the consequence of defeating interlocks/safety guards. The influence of safety culture maturity on risk perception and the attitude and belief that productivity takes priority over safety were also identified as important predisposing factors.

Enabling factors are objective aspects of the environment or system that block or promote the uptake of risk controls. Enabling factors were the most frequently identified in the literature and secondary data. These included productivity demands, time delay associated with the use of safety devices, lack of resources, ergonomic issues, e.g. poor visibility, and the need to defeat interlocks during troubleshooting and maintenance. Lack of worker engagement and the appropriate skills/training, policies and procedures were also identified as enabling factors.

Reinforcing factors are environmental features that reward or punish compliance-related behaviour. A variety of reinforcing factors emerged from the literature review and secondary data. The need for a healthy organisational culture with a good safety management system and good communication clearly emerged. A further reinforcing factor was a lack of management commitment to health and safety and a belief by employees that management encourage overriding safeguards to meet production goals. Finally, the findings highlighted a lack of enforcement; no negative consequences are applied to prevent these behaviours i.e. reprimands, peer disapproval. Conversely, tampering with safety devices acts as positive reinforcement for operatives, as the benefits associated with these behaviours include working faster, improving visibility, and dealing with faults more efficiently. This presence of positive reinforcement and absence of negative consequences means that tampering is more likely to occur.

ISSUES FOR CONSIDERATION

HSE has reviewed accident and enforcement data to determine the scale of the problem in prevalence and severity of incidents and accidents both within the UK and internationally. HSE statisticians have also carried out an analysis of the accident/incident and enforcement (COIN) database to identify the extent and prevalence of enforcement action within the UK on defeating of interlocks when using CNC machines. HSE Corporate Science Engineering and Analysis Directorate (CSEAD) conducted this work and the findings (reported in Appendix 5 of this report) will be taken into account by the HSE/HSL project team when planning the next phase of this research.

The conclusions drawn from this literature review are based largely on findings from previous papers. The majority of these focused on general machine safety management, rather than CNC machines and interlock defeating specifically. Furthermore, the sample employed in the secondary qualitative analysis was selected for the level of information the reports contained. Consequently, the sample was small and cannot be regarded as representative of the wider population of CNC machine users. There are however findings that have identified areas for more exploration in the interviews with managers/supervisors and the operative focus groups planned in the next phase, namely:

- Exploration of possible reasons why production, troubleshooting and maintenance activities appear to be more susceptible to the defeating of interlocks, e.g. the influence of any associated cost-benefit appraisals with these activities.

- Investigation of the influence that such a range of consequences (from relatively minor injury (e.g. finger laceration) to fatality) may have upon managers, supervisors and operatives' risk appraisal and perception processes. Therefore, whether organisations and individuals fully appreciate/understand their personal susceptibility, the potential severity of consequences associated with the defeat of interlocks, and potential strategies to raise awareness.

- In-depth exploration of the factors likely to influence operatives' health and safety behaviour - predisposing; enabling; and reinforcing. Whilst enabling factors were the most frequently cited in the literature and secondary data, this may be due to the focus of the discussions in the papers reviewed, and the objective nature of the COIN and RIDDOR data. All three factors are relevant for understanding operative behaviour in the defeating of interlocks on CNC machines, and should therefore be explored in subsequent interviews and focus groups.

- Examination of whether certain factors, perhaps unknown at this stage, play a more prominent role in influencing operative behaviour when using machine guarding compared with general health and safety management.

- Identification of appropriate and pragmatic strategies to improve health and safety performance related to the use of CNC machines and interlocks compared with those identified in the literature (e.g. improvements in design of interlocks/machines, raising awareness of the risk, management training etc).

- Inclusion of engineering, plastics and woodworking industries in the next phase of the research as no industry-specific issues have been identified so far; rather common issues seem prevalent across industry.

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1. INTRODUCTION

1.1 RESEARCH OVERVIEW

The Health and Safety Laboratory (HSL) has been commissioned by HSE to carry out research to explore the reasons that operatives defeat interlocks on Computer Numerical Control (CNC) machines.

An interlock is as a switch or other device that prevents activation of a piece of equipment when a protective door is open or some other hazard exists (McGraw–Hill, 2003). Effectively, interlocks are the same as the mechanisms found on many household appliances, e.g. the system by which items such as washing machines cannot be opened whilst they are operating. An interlock may prevent opening by locking the system whilst it is operating, or it may trigger the power to the drive to be cut if a door is opened. There are different levels of interlock and levels of safety they provide. The determining factor in their use is the level of risk and hazard associated with a machine. Box 1 contains some other useful definitions relevant to the context of this work.

- Turning machine - machine tool in which the principal movement is the rotation of the work piece against the stationary cutting tool(s).
- Manual control - mode of operation where each movement of the machine is individually started and controlled by the operator.
- Manually controlled turning machine - turning machine for which process steps for the machining are controlled or started by an operator without support by a numerical control (NC) machining program.
- Computer numerical control (CNC) - automatic control of a process performed by a device that uses numerical data while the operation is in progress. CNC systems can be fitted to previously manually operated machine tools, such as milling machines or lathes.

Box 1 Useful definitions

1.1.1 Policy background

The defeating of interlocks on CNC and other (manual) machines has been identified by HSE as a common problem in small and medium sized enterprises (SMEs) and attracts a significant level of enforcement action. Current understanding suggests that despite enforcement action, operatives may continue to defeat interlocks. Such behaviour[29] has the potential to result in serious personal injury and fatalities from entanglement and ejection. Tasks that operatives perform when they defeat interlocks include setting/proving, polishing/finishing and swarf removal. Experience indicates that the practices often repeat over time within the same organisations and within similar industries.

[29] In this context, behaviour refers to an overt visible action or practices that expose an individual to health and safety risks. Behaviour, in turn, is influenced by a range of factors that occur at an individual, social, and organisational level. The terms action and practices are used in this brief to refer to behaviour.

1.1.2 Current regulation and guidance

Employers have legal duties regarding machinery and interlocking/guarding devices. The main set of regulations detailing an employer's duty is the Provision and Use of Work Equipment Regulations (1998) (PUWER). In accordance with PUWER, (1998) employers and others must ensure that:

- Suitable equipment is provided for the jobs involved;
- Equipment is safeguarded to prevent risks from mechanical and other specific hazards;
- Equipment is provided with appropriate and effective controls;
- Equipment is maintained in good working order and repair;
- Maintenance is carried out safely;
- Information and instruction are adequate;
- Training is provided for operators and supervisors.

There are also requirements under the Supply of Machinery (Safety) Regulations (2008), which affect the manufacturers and suppliers of machinery.

Inspection and enforcement action by HSE inspectors is determined by business plans designed to deliver HSE's overall strategy. Inspectors will treat the defeating of interlocks on CNC machines as a 'matter of evident concern' (OC18/12 version 3) and deal with it accordingly. However, it is acknowledged that incident and accident analysis reports can differ in their nature and level of detail, making it difficult to distinguish between breaches involving CNC and manual machines.

An understanding of the issues relating type of machines, actual practice and associated incident/accidents is needed for HSE to evaluate the effectiveness of its current approach to regulating the control of risks from the defeating of interlocks. Research is needed to enable HSE to ensure its guidance and enforcement approach is towards those behaviours which are more likely to result in good practice on the part of duty holders and operatives, and most likely to result in reducing incidents/accidents.

1.2 AIMS AND OBJECTIVES

The overall aim of this research is to identify the reasons, in terms of human factors, why operatives defeat, or are motivated to defeat, machinery guarding particularly safety interlocks provided in a variety of CNC machines. Key research questions are:

- What factors influence operatives' decisions and practices in relation to the over-riding / defeat of machinery guarding, particularly the safety interlocks provided to a variety of CNC machines?
- What is the extent of the problem of defeating interlocks on CNC machines?

From answering these research questions a better understanding of operative behaviour when defeating interlocks will be gained. This will help towards the desired outcome of allowing HSE to provide better guidance to its inspectors and industry on levels of acceptable risk. In turn, this should help to improve compliance behaviour and possibly improve machinery design as it is anticipated the research may have implications for how operatives interface with machines. There is also a cross-cutting aspect to this work. In addition to engineering, interlocks are defeated on many CNC and manual machines in other industries, such as plastics and woodworking industries. Incorporating research in these industries into the current project aims to provide some indication and insight into common issues, as well as any industry-specific issues.

The research consists of two phases, each with specific objectives. This report marks the completion of phase 1, the objectives for which are detailed below. This will enable HSE to take stock of the outcomes of phase 1 before commencing phase 2 and assess whether further primary evidence is needed before embarking on phase 2 (manager and supervisor interviews and operative focus groups).

1.2.1 Phase 1 objectives

In accordance with the HSE customer's briefing, phase 1 reviews existing evidence to identify the extent and nature of the problem of defeating interlocks on CNC machines. Phase 1 objectives include:

- **Strand 1**: To review the existing literature identified by HSE customers, collate and review additional literature on the topic of the reasons (in terms of human factors) why operatives defeat machinery guarding, particularly safety interlocks;
- **Strand 2:** HSL to carry out a qualitative analysis of a subset of the accident/incident data from RIDDOR and COIN;
- **Strand 3**: HSE (CSEAD) to review accident/incident and enforcement (COIN) data to determine the scale of the problem, in terms of prevalence and severity of incidents and accidents, both within the United Kingdom and internationally;
- **Strand 3**: HSE statisticians to carry out an analysis of the RIDDOR database to identify the number of reported incidents related to the defeating of interlocks on CNC machines;
- To identify common issues spanning the three industries selected by HSE of engineering, plastics and woodworking, as well as any industry-specific issues.

1.3 ABOUT THIS REPORT

This report summarises the findings from the initial fact finding stage (phase 1) of this two-year project. The sections that follow give an explanation of the methodology adopted for the literature review and analysis of the secondary qualitative data, a summary of the key factors that emerged from the literature and qualitative data and suggestions of areas to focus on in phase 2 of this research. This report also contains the work conducted by HSE CSEAD/statisticians (see Appendix 5 of this report). This report will be included as an annexe of the final report of the full research. Phase 2 and is planned for delivery in summer 2012.

2. METHOD

2.1 RESEARCH DESIGN

A broad-based evidence review was conducted in phase 1, which draws on evidence from a wide variety of sources as summarised in Figure 1. A mixed methods approach using both qualitative and quantitative approaches was followed. This enabled the researchers to identify and review a broad spectrum of the existing evidence from both subjective and objective sources. Qualitative approaches included a literature review and analysis of secondary qualitative data taken from HSE's COIN and RIDDOR databases. HSE CSEAD conducted quantitative analysis on the COIN and RIDDOR data. **N.B Strand 2: Secondary data analysis: quantitative was conducted by HSE CSEAD and has been reported separately in Appendix 5 of this report.**

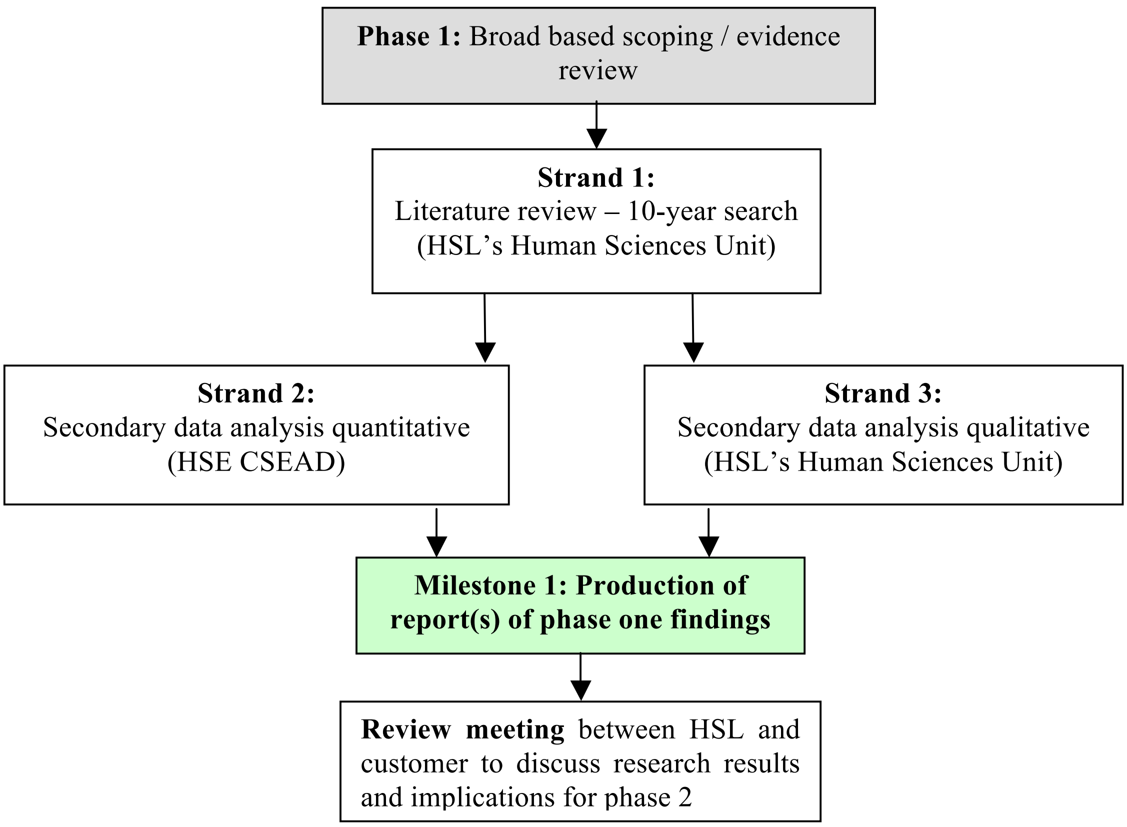

Figure 1 Research design for phase 1

Literature reviews help to summarise detailed information and enable us to establish existing knowledge within an area, draw out broad conclusions about a topic, and to develop a good understanding of that area to inform and suggest further research. In addition to reviewing literature, the focus of a broad-based evidence review is on casting a wide search process to capture all relevant data. This method allows researchers enough flexibility to search a variety of issues, as well as allowing for a creative and innovative approach to be adopted. Consequently, prioritisation is given to the scope of information rather than scientific rigour. A systematic review therefore was decided to be unsuitable for this research. This is further supported by the apparent scarcity of research in the area.

2.2 DATA COLLECTION

2.2.1 Strand 1: Literature review

2.2.1.1 Searches

HSE's Information Service (IS) carried out a search of relevant literature. The literature search aimed for high precision wherever possible and was structured so that the strategy encompassed relevant concepts to cover the research questions. To ensure that search terms yielded the correct amount and quality of data, the HSE technical customer was consulted (see Appendix 1 for search terms and databases searched).

CNC machines with interlocks have been in operation for many years. Whilst there have been step changes in technology, no single defining developments which would obviously set limits on any search could be identified. Additionally, it may be anticipated that the performance shaping factors that motivate operatives to defeat interlocks may be relatively constant in spite of the slowly evolving technologies they work with. Given this and the likely paucity of data, the decision was made by HSE/HSL to adopt a relatively long timescale for the literature search. The IS team were therefore asked to search for all relevant literature dating back ten years.

As anticipated there was a paucity of literature identified; several databases returned no information. Table 1 details the number of abstracts identified and the associated databases.

Table 1 HSE database search results

Database/information source	Number of Abstracts
HSELINE, RILOSH, OSHLINE, CISDOC, and NIOSHTIC	24
Healsafe	9
Web of Science	4
Ergonomics Abstracts	11
World Reporter	4
Psychinfo	13

2.2.1.2 Selection of Papers

A sift of abstracts resulted in a total of 25 full papers being requested. Ten papers were rejected at the first sift as these were not relevant to the current research. In addition to these 15 selected papers , the HSE customer identified one further paper. This was an article written in German and consequently had not been identified by the initial search of only English language papers. This article was translated by HSE translation services. The final number of papers reviewed was therefore 16.

2.2.2 Strand 3: Secondary data analysis: qualitative

HSL collected qualitative elements of the secondary data (COIN and RIDDOR) generated by HSE CSEAD during Strand 2 (i.e. any text/comments written in the COIN incident/enforcement database and RIDDOR reports). All these cases were related to CNC machines. See Appendix 1 for search terms used to identify relevant cases.

The COIN search produced a total of 241 cases, and RIDDOR search a total of 20 cases. Researchers originally intended to select a random sample of 20% of the 241 COIN cases to review, the aim being to determine where possible the nature of incidents/accidents and the underlying factors and reasons behind them. However, on closer inspection it became apparent that a high proportion of these randomly selected cases lacked the necessary level of information (e.g. only stated that an enforcement or improvement notice had been served on a specific machine but omitted details of reasons and did not refer to any injuries/incidents). To ensure that all relevant information from the 241 cases was captured a comprehensive inspection of all cases was conducted. Twenty-three relevant cases with the required level of textual detail and information were identified. Cross checking of the COIN and RIDDOR data sets ensured that there was no duplication (e.g. a case being counted in both data sets). This yielded a combined total of 43 RIDDOR and COIN cases for the qualitative analysis.

2.3 DATA ANALYSIS

2.3.1 Strand 1: Literature review

Once all relevant literature had been identified, two researchers conducted an initial review of a random selection of 25% (n=4) of the papers. During this stage, a list of relevant themes was generated. These themes were used to create an initial framework for data capture and analysis. The information was therefore grounded in the literature obtained, rather than a structure being imposed upon it.

Once the framework had been agreed and spreadsheet established for data entry, two researchers jointly reviewed the first paper. This enabled the production of data extraction guidelines to ensure consistency between researchers. . Two researchers reviewed the remaining papers independently. To ensure quality and consistency in the data extraction process, a third researcher reviewed a random sample of around a third of the papers (n=5). This check confirmed good inter-rater reliability and consistency.

Once all papers had been reviewed, the key themes were mapped against an established theoretical framework, the PRECEDE Model (Green, Kreuter, Deeds & Partridge, 1980). This model is an appropriate theoretical framework to adopt for this research, as it is capable of accommodating a disparate range of individual and organisational factors. Unlike traditional models of behaviour change, it goes beyond individual-level variables to consider important social-environmental factors and the context within which behaviour occurs (Sheehy & Chapman, 1987; Smith & Beringer, 1987; Dejoy, 1996). According to the model, three sets of diagnostic factors drive behaviour.

Predisposing factors are characteristics of the individual (e.g. knowledge, risk appraisal, beliefs) that facilitate or hinder the uptake of risk controls. **Enabling** factors refer to objective aspects of the environment/system that block or promote the uptake of risk controls. These include; skills, availability and functionality of appropriate machines and other equipment, work demands, visibility of operating field, policy and procedures, training, communication, current legislation/guidance, employee involvement, benefits and costs (e.g. time delay) associated with the use of risk controls. **Reinforcing** factors concern environmental features of systems that reward or punish compliance related behaviour (any reward or punishment that follows or is anticipated as a consequence of behaviour). These refer to e.g. the prevailing health and safety climate, observable management commitment to health and safety, prior experience of enforcement, production benefits, peer and employee attitudes/knowledge. This model does not claim to have watertight reliability and validity for all possible occupational contexts. Rather, it provided a scientific framework for selecting important contributors to operative's behaviour in relation to the defeating of interlocks.

2.3.1.1 Strand 3: Secondary data analysis: qualitative

The aim of this analysis was to determine where possible, the nature of incidents/accidents and the underlying factors and reasons behind them. An HSL researcher examined the 43 relevant cases retrieved. Each case contained two types of information:

- Categorical data pertaining to a range of classification criteria e.g. geographical location, industry, type of injury, activity, machine type etc;
- A textual summary of the information supplied by the reporting party comprising details of the incident.

Key themes that emerged from the categorical data and textual summaries were organised into an excel spreadsheet. Two researchers developed the initial framework to promote objectivity whilst ensuring that the themes identified in the literature review were incorporated.

The categorical data was analysed by a sole researcher using content analysis – (a simple count of the frequency that key themes emerged in order to discern the extent to which that category applied to all cases. The textual data was examined to identify relevant information on the following:

- Predisposing factors i.e. characteristics of the individual such as knowledge, beliefs, attitudes, values etc;
- Enabling factors i.e. objective aspects of the environment/system that block or promote the uptake of controls e.g. skills, competence, accessibility of machines etc;
- Reinforcing factors i.e. any reward or punishment that follows/is anticipated as a consequence of behaviour e.g. safety climate/culture, production benefits etc.

This enabled comparisons to be drawn between these findings and those from the literature review, structured around the PRECEDE Model. A second researcher checked a sample of the data (20%) for accuracy and to ensure inter-rater reliability.

3. FINDINGS

3.1 STRAND 1: LITERATURE REVIEW

The findings of the current literature review are structured according to the themes identified.

3.1.1 Overview of papers

As anticipated there was a lack of relevant literature. Only two papers explicitly addressed the factors that influence the defeating of safety interlocks on different types of machines, which included Computer Numerical Control (CNC) machines, and the prevalence of such behaviour (Apfeld et al, 2006 & Luken et al, 2006). Both these papers reported on the same piece of research. However, all the papers reviewed contained relevant information for machine safety as they highlighted the multiple influences upon operative behaviour when defeating safeguards and provided suggestions to address this.

Of the 16 papers reviewed, six were published in trade journals/specialist magazines (Elliot, 2003; Freedman, 2004; Lippert & Brown, 2004; McConnell, 2004; Roudebush, 2005; Sherrard, 2007), seven were academic peer-reviewed journal papers (Dzwiarek, 2004; Luken et al, 2006; Samant, Parker, Brosseau, Pan, Xi, Haugan, & The Study Advisory Board, 2006; Brosseau, Parker, Samant & Pan, 2007; Etherton, 2007; Chinniah, 2009; Parker, Brosseau, Samant, Xi, Pan, Haugan, & The Study Advisory Board, 2009). One was a research report (Apfeld et al, 2006), one was a fatal accident investigation report (Department of Health State of New York, 2004), and one was a book chapter that discussed how human factors can be used to understand and improve machine safeguarding (Adams, 2000).

Eleven of the articles were from the United States of America (USA) (Elliot, 2003; Freedman, 2004; Lippert & Brown, 2004; McConnell, 2004; Department of Health State of New York, 2004; Roudebush, 2005; Samant et al, 2006; Brosseau et al, 2007; Etherton, 2007; Sherrard, 2007; Parker et al, 2009). One article (Chinniah, 2009) was from Canada and one (Dzwiarek, 2004) from Poland. Two articles from Germany (Apfeld et al, 2006 & Luken et al, 2006) reported on the same piece of research. Finally the book chapter (Adams, 2000) did not specify a specific country. Whilst all evidence reviewed came from the USA or Europe it is reasonable to apply this evidence to a UK context due to the similarity in types of machines and operation modes.

Samant et al, (2006); Brosseau et al, (2007) and Parker et al, (2009) reported on various phases of the same piece of research within the USA metal working industry. One article (Chinniah, 2009) centred on the manufacturing industry and the report from the Department of Health State of New York (2004) was from the retail sector. The remaining nine articles were applicable to machine use cross industry.

3.1.1.1 Academic journal papers

From the seven academic journal papers included, three focused on one study; the **design, implementation and evaluation of interventions aimed at improving machine safety practices** in small metal fabrication businesses (Samant et al, 2006; Brosseau et al, 2007: Parker et al., 2009). Specifically, Samant et al (2006) carried out a baseline evaluation of machine guarding and related safety programs and practices in a sample of 40 small USA metal working businesses. The baseline evaluation involved the use of checklists to assess machine guarding practices through observations, and a safety audit to evaluate three aspects of overall safety (e.g.

general environment, administrative and management policies and employee practices, such as use of goggles). Building on this study, Brosseau et al (2007) designed a series of interventions, tailored to both business owners and employees, which aimed to improve the management of machine-related hazards and prevent injuries in small metal working businesses. Business owner interventions were aimed at enhancing knowledge on machine safety, encouraging the adoption of relevant safety procedures, involving employees in decision-making on machine safety, as well as promoting improvements in machine guarding. The intervention activities for employees focused on improving attitudes towards machine safety, including following safety procedures, using guards and other safety devices and participating in health and safety decision-making. In addition, the interventions focused on making safety committees more effective by building members' knowledge and skills. The outcomes of these interventions were reported in a subsequent study by Parker et al (2009). This paper concluded that participating companies' safety scores had improved significantly during the course of the interventions.

A further three academic papers focused on identifying **the prevalence of bypassing safety interlocks and exploring potential underlying causes** using surveys (Apfeld et al, 2006; Luken et al., 2006) or analysing accidents involving the improper functioning of machine control systems (Dzwiarek, 2004). The remaining three academic papers provided **general discussions on machine safety**. This included an overview of some of the most commonly observed problems linked to machine safety in the manufacturing sector in Quebec (Chinniah, 2009), and discussing the importance of using risk assessments in conjunction with machine safety standards to prevent accidents and injuries (Etherton, 2007).

3.1.1.2 Specialist/practitioner magazines

There was a similar breadth of issues addressed by articles published in the specialist/practitioner magazines. These focused on the **importance of considering machine safety, and particularly safeguards early on at the design and production stages** (Freedman, 2004), and providing good practice regarding the effective implementation of lock/tag out and/or machine safeguarding programmes (Elliot, 2003; Lippert & Brown, 2004; McConnell, 2004). In addition, some papers stressed the **importance of using risk assessments** to help guide the identification of appropriate machine safeguards (Freedman, 2004; Roudebush, 2005). Finally, several articles discussed factors that influence the defeating of machine safeguards and provided a number of suggestions regarding how such instances could be reduced (Adams, 2000; Freedman, 2004; Apfeld et al, 2006; Luken et al, 2006; Etherton, 2007; Sherrard, 2007; Chinniah, 2009).

3.1.1.3 Research reports

One research report (Apfeld et al, 2006) **explored the prevalence of bypassing safety devices in different types of machines (including CNC machines) and the factors that influence operators' decisions in over-riding machine safeguards.** This report provides a comprehensive account of the same research conducted in Germany that Luken et al (2006) provide an overview of in their paper. Given the direct relevance of this study to the current research, in addition to discussing the key findings of Apfeld et al (2006) within the appropriate themes detailed below it was considered appropriate to provide a more detailed summary of this paper. This can be found in Appendix 2.

3.1.2 Extent of the problem

One of the research questions addressed by the current review involved identifying the extent of the problem associated with defeating of interlocks, specifically on CNC machines.

The research reported by Apfeld et al (2006) and Luken et al (2006) was carried out by an interdisciplinary team in Germany and provided an insight regarding the prevalence of safety device manipulation in companies, as well as the types of machines (such as CNC machines) and protective devices that are most frequently tampered with. The research team carried out two surveys: the first survey consisted of a general questionnaire distributed to 1,000 health and safety experts (e.g. technical advisory staff and safety engineers). This questionnaire assessed how often manipulations happen, and the frequency of manipulations depending on the type of safeguard and machine operational mode. The second survey focused on a detailed analysis of specific instances of tampering observed in plants based upon an investigation of 202 machines. The findings showed that tampering is widespread i.e. 37% safety devices are manipulated. Machines tampered with consisted of machining centres, presses and CNC milling machines and lathes. Fifty eight per cent of the machines had been constructed post-1995 suggesting that newer machines are as likely to be tampered with. Movable separating devices with position switch or locking and mechanical, non-moving separating protective devices are most prone to tampering. Tampering activities typically included removing and/or inserting separated activators, and bypassing and/or dismantling switches. Tampering activities are most frequently observed during automatic and installing/setting up modes followed by programming, program testing and test runs and re-adjusting modes. Troubleshooting was also identified as an activity associated with manipulation/defeating of safeguards. A full account of these findings may be found in Appendix 2.

These findings are supported by other studies suggesting that bypassing safety devices is a widespread phenomenon with potentially serious consequences. Etherton, (2007) claimed that machine-safeguarding violations are among the top ten violations reported by USA safety standards inspectors. Specifically, machine-guarding violations were ranked fifth among the top ten serious violations (i.e. where violations result in a substantial probability that death or serious physical harm could result) with a total of 2,889 violations reported. Investigations of amputation injuries from 1995-97 in Minnesota, USA, found guards not in use in two-thirds of machine related injuries (Boyle et al, 2000, cited in Freedman, 2004). Freedman (2004) claimed that bypassing safeguards is one of the most frequent causes of machine related accidents in automated production today, however no statistics were provided to support this claim. It must be noted that none of these reports were for CNC machines however.

Additional statistics show that of the 1,797 inspections carried out in 2003 by Minnesota Occupational Safety and Health Association (OSHA) in manufacturing businesses, 15% resulted in citations for violations of machine guard requirements (Zaidman, 2004, cited in Samant et al, 2006; Brosseau, et al., 2007). The baseline observations reported in Samant et al (2006) found generally inadequate machine guarding practices and machine safety programs. More than 40% of devices required for adequate guarding were missing or inadequate and 35% of required safety programs and practices were absent.

Furthermore, inadequate use of machine safeguards appeared to be a contributory factor in amputations in the woodworking and metalworking industrial sectors in Minnesota. In two thirds of incidents involving amputations in these sectors, machine safeguards were not in use (Samant et al, 2006). The reasons cited for inadequate use of safeguards included activation of unguarded controls, inadequate or defective guards or the absence of guarding (Boyle et al, 2000, cited in Samant et al, 2006). There was a lack of data on the type of machine most likely to cause amputation but the authors cited studies (e.g. Stanbury, 2000, cited in Samant et al, 2006) that have identified power presses, metal cutting saws and lathes, punch presses and drilling machines as hazardous, although it was not clear how these distinctions were made, neither was it possible to determine if these included CNC machines.

Finally, the defeating of safety devices was identified as a contributory factor in machine-related incidents across a representative sample of factories in Poland. Dzwiarek (2004) analysed 700 incidents (that occurred during the period 1996-2002) relating to the improper functioning of machine control systems in order to identify the causes underlying these incidents. Incorrect worker behaviours, such as attempts at defeating safety systems, were implicated in all the accidents that were analysed. However, defeating safety systems was only one of several other causes that were implicated in these incidents (such as inadequate responses to sudden events and use of working procedures that were inconsistent with safety requirements) (Dzwiarek, 2004). As a result, it was not possible to determine the prevalence of 'defeating behaviours' over other types of behaviours in the causation of the incidents.

Key findings from the literature relating to the extent of the problem are presented in Box 2.

- Bypassing safety devices is a widespread phenomenon with potentially serious consequences e.g. fatality, amputation.
- Machine-safeguarding violations are widespread in Europe and among the top ten violations reported by USA safety standards inspectors.
- The literature cited generally inadequate machine guarding practices and machine safety programs.
- Reasons cited for inadequate use of safeguards included activation of unguarded controls, inadequate or defective guards or the absence of guarding.
- A variety of machine types are frequently tampered with including e.g. machining centres, milling machines, lathes.
- Machine setting, maintenance and troubleshooting are associated with tampering activities.
- Movable separating devices with position switch or locking and mechanical, non-moving separating protective devices are most prone to tampering.
- Tampering activities typically include removing and/or inserting separated activators, and bypassing and/or dismantling switches.
- Machine age does not seem to impact the defeating of safety systems; newer machines are as likely to be tampered with as older ones. However, new machines are being developed which are very difficult/impossible to tamper with.

Box 2 Key findings: extent of the problem

3.1.3 Factors influencing operative behaviour

A variety of influences on operative behaviour regarding the defeating/attempting to defeat machinery interlocks/guards were identified. As such, a wide range of psychological (e.g. self-efficacy/confidence to control risks, knowledge/understanding of risks), social (e.g. safety culture, general attitudes towards, and beliefs about machine risks), organisational (e.g. training, time pressures, attributed responsibility for risk management) and environmental factors (e.g. the interface with machinery and safeguards) were found to influence behaviour. In order to structure the findings and aid identification of the issues to focus upon in phase 2, these factors have been categorised according to the PRECEDE model (Green, Kreuter, Deeds & Partridge, 1980) (see Method: section 2.3.1) for details of this model).

This section provides a summary of the literature identified as relating to each overarching factor – predisposing, enabling or reinforcing. It should be recognised that in some instances factors may overlap. For example, safety climate may influence an individuals values and beliefs and therefore operate as both predisposing and reinforcing factors. To aid clarity, influences upon operative behaviour have been grouped under one (the most appropriate) factor. Finally, it must be acknowledged that the strength and type of available evidence available for this literature review was limited. Therefore, the potential causal role and strength of influence on operative behaviour for each factor cannot be fully ascertained.

3.1.3.1 Predisposing factors

There was a paucity of information regarding predisposing factors in the literature. It was possible, however, to identify several important factors that may influence machine safety and the defeating of safety devices/interlocks.

Operative's knowledge of the risk and the associated consequences emerged as an important influence on behaviour. Ignorance/lack of knowledge of the severity of the consequences of defeating interlocks was considered to contribute to unsafe behaviour (e.g. Adams, 2000; Apfeld et al, 2006; Luken et al, 2006; Sherrard, 2007). The survey reported by Apfeld et al. (2006) and Luken et al (2006) found that operators tend to underestimate the risks associated with bypassing safety devices suggesting that they receive inadequate training and information on this issue. Similarly, the report on the fatal accident investigation (Department of Health State of New York, 2004) found that many employees reported using and observing the machine involved in the incident working with the safety gate open. This suggests that employees may not have been aware of the importance of interlocks for their safety.

The influence of **poor risk perception and appraisal** upon behaviour was apparent in several papers. The German metal shop study (Apfeld et al, 2006 & Luken et al, 2006) found that machine operators showed a significant underestimation of the heightened hazard caused by manipulation of safety devices. Fifty eight per cent of operators reported that the danger resulting from tampering was 'low' and 'very low'; these responses were in sharp contrast with those of the supervisory personnel and health and safety specialists who rated the dangers as 'high' or 'very high'. On the whole, operators did not view the tampering of safety devices as hazardous. A third of operators viewed protective devices as obstructions in carrying out the work and did not feel that they were necessary. Over 80% of operators did not feel unsafe in operating a machine that has been manipulated and about 29% were willing to accept the risk of a potential accident. Chinniah's (2009) observations in Quebec factories supported this view, finding that a reason for the bypassing of safety devices was operators underestimating the risk.

With regard to risk perception and appraisal, Chinniah (2009) suggested that as operators have to identify risks whilst operating machinery, experienced workers tend to get used to workplace hazards and no longer perceive them as hazards. Conversely, novice and inexperienced workers are not aware of the hazards. The observations conducted in the Chinniah (2009) study found that workers may identify some of the hazards associated with complex machines but often fail to identify all hazards associated with a particular activity.

Etherton (2007) reviewed risk theories, machine risk assessment standards and risk estimation tools that can be used to inform machine risk assessments. Whilst this paper did not specifically discuss factors that influence the defeat of interlocks/safety devices, individuals' evaluations of risks and the **influence of safety culture** on risk perception were seen as important factors guiding individual actions. Similarly whilst providing advice for safety leaders on how to implement lock/tag out programs, Elliot (2003) did not discuss factors influencing behaviour directly, yet predisposing factors can be implied from the suggestions made. These included the need to raise awareness of risk, consequences and personal susceptibility.

Finally, whilst the use of risk estimation tools may be valuable for this issue, Chinniah (2009) argued that safety practitioners have identified several problems with risk estimation tools. Such tools are found to vary in design and parameters (e.g. the types and number of parameters that each tool uses to define risk). Results vary when different tools are applied to the same situation and when different users apply the same tool to the same situation. There can also a difference between the risk judgments that people are called to make when responding to a questionnaire and their experience of risk when actually operating machinery. Risk estimation is therefore viewed as subjective and the validity of results is often questioned.

3.1.3.2 Enabling factors

A variety of enabling factors were identified in the current review (e.g. McConnell, 2004; Samant et al, 2006; Brosseau et al, 2007; Parker et al, 2009). These included **financial pressures**, a **lack of resources** and time, **resentment of a regulatory environment**, **poor worker/machine/guard interface**, **old equipment** that is difficult to retrofit with safety devices and a **lack of on site staff with specialised knowledge** in small businesses. The full range of enabling factors identified is discussed below.

Adams (2000) drew on cost/benefit models to explain why workers may engage in unsafe behaviours such as overriding safeguards. The author argued that **individuals weigh up the costs and benefits of engaging in unsafe acts**. In relation to defeating safeguards, perceived benefits may be; less time spent on task and possible positive feedback from supervisor on productivity, acceptance by peers and excitement from taking risks. Costs may include; increased risk of injury to self and others, disciplined if caught and the stress associated with knowing that an unsafe act was committed. The author argued that whilst there is little or no scientific research on the cost/benefit models in the context of machine safeguarding, applying human factors and ergonomics principles in the design of safeguards could help reduce the perceived benefits of defeating safety systems.

Adams (2000) suggestion that **production requirements, job pressure or stress** are important influences upon operative behaviour and may be the reason why workers are motivated to bypass safeguards, was mirrored by several papers. Sherrard (2007) examined machinery related accidents and their causes. **Productivity pressures and the conflicting demands of production versus safety** were highlighted as important influences. McConnell (2004) also argued that safeguards slow production or make equipment more difficult to operate. In the research reported by Apfeld et al (2006) and Luken et al (2006), survey respondents were asked about their reasons for tampering with safety devices. Reasons given included gaining time, time pressure on performance and raising productivity.

Lippert and Brown (2004) discussed the Occupational Safety and Health Association (OSHA) standard in the USA that requires companies to have a lock/tag out (LOTO) program and how to successfully implement such a program. Whilst this paper did not discuss influences on operative behaviour directly, factors enabling safe behaviour may be implied from their suggestions. This includes the need for planning, clear policies and procedures and the provision of adequate and appropriate **equipment and training**. Samant et al's (2006) baseline evaluation of metal working shops cited the importance of **an effective safety management system** characterised by the presence of clear policies and procedures (e.g. lock out procedures), machine use and safety training and good written records.

Brosseau et al (2007) followed up Samant et al's (2006) baseline evaluation by developing interventions to improve behaviour. Interventions for owners were designed to increase knowledge about machine safety, encourage adoption of safety procedures and motivate improvements in guarding. Interventions for employees focused on building the knowledge and skills of health and safety committee members. So **employee involvement** was viewed as an important enabling factor. If not already in existence, the business was asked to form a health and safety committee. Each committee participated in educational sessions by a peer educator designed to build knowledge on machine safety and provide opportunity for hands on evaluation and decision-making. The follow up study by Parker et al (2009) supported the value of employee involvement. High levels of engagement led to greater knowledge and fewer negative outcomes. Guarding procedures and lock/tag out training records were found to be significantly associated with the existence of a safety committee. Those companies that showed the greatest improvement were the ones that did not previously have safety committees but had developed them as part of the intervention. Apfeld et al (2006) also discussed employee involvement, suggesting that operators might defeat machine safeguards because they hinder work processes and this may be because operators are not consulted when new machines are purchased.

A lack of, or inappropriate operative **supervision and training** was highlighted as an important factor in the literature (e.g. Department of Health State of New York, 2004; Dzwiarek, 2004; Apfeld et al, 2006; Sherrard, 2007; Chinniah, 2009). Apfeld et al. (2006) and Luken et al (2006) found a lack of training and awareness regarding tampering of safety devices. Over 20% of operators had not received any instructions or training and in just under half of the companies surveyed (45%) tampering was not discussed. Moreover 12% of respondents reported that using protective devices required a re-learning of how to carry out the work activity.

Dzwiarek (2004) analysed 700 accidents resulting from the improper functioning of machine control systems to identify the underlying causes. The authors concluded that workers' incorrect behaviour (including attempts to override safety systems) should be addressed by appropriate supervision and training. Sherrard (2009) discussed a lack of training and knowledge specific to the different types of machines, processes and guards that operatives use. Chinniah (2009) in a study based in Quebec, identified a need for all relevant groups to be trained by providing employers, operatives and engineers with training in lockout procedures and machine safety. The author specifically argued that there is a lack of expertise regarding machine safety due to no formal training in this field in Quebec engineering schools. Tangible evidence for the importance of appropriate training came from the investigation of a fatal accident (Department of Health State of New York (2004). This report suggested that a lack of training and knowledge was an influencing factor in this incident. The company did not have the appropriate training video or manual for the machine and important safety instructions and training were not provided to employees/managers. Additionally, there were inadequate written procedures that did not cover interlocks and how to use them e.g. when clearing a jam.

Knowledge and skills of duty holders was also identified in the literature as important. Samant et al's (2006) baseline evaluation indicated that most owners of the metal shops studied were aware of the importance of machine safety but lacked knowledge of regulatory requirements. Managers were found to have a limited understanding of lockout and other safety related programs. For example, managers were able to furnish records of lockout training in 60% of shops but only 13% had an established lockout program indicating a dissonance between understanding and implementation of safety requirements. The follow up study by Parker et al (2009) supported the importance of training and equipping duty holders with the appropriate information and skills. Process evaluation of the intervention implemented found that 94% of managers felt that the programs and materials provided (e.g. hazard identification, control knowledge, training materials) helped to improve their knowledge of health and safety.

A variety of influences relating to **the design, accessibility, functionality and maintenance of machines and safeguards** emerged from the current literature review (e.g. Adams, 2000; Apfeld et al, 2006; Luken et al, 2006, Sherrard, 2007; Chinniah, 2009). Adams (2000) claimed (although no reference was given to evidence this claim) that common complaints associated with the use of safeguards included:

- Safeguards are too hard to see through or around (visibility);
- Safeguards are too heavy to move or too big to reach around or over;
- Safeguards are difficult/take too much time to remove or replace;
- Operators become tired of removing safeguards every time the machine needs lubrication;
- Safeguards get in the way of clearing jams;
- There are too many accidental trips of the emergency stop or interlock system;
- Protruding bolts and sharp edges on safeguards causing clothing to get caught/skin cuts.

More robust were the claims of Chinniah's (2009) overview of the most commonly observed machine safety problems in the manufacturing sector in Quebec (observations were made > 50 factories in the manufacturing sector). Chinniah argued that system design is vital and the integration of safety devices should be considered when upgrading machines. Similar problems to those cited by Adams (2000) were observed e.g. the guards are not at the correct height or position from the hazard, the guards needed to be removed to undertake maintenance or because they hindered normal pace of work to speed up production. Basic safety principles were often not applied e.g. safety switches were not fastened properly, guards were not held securely in place making their removal easier or there was no separation of safety related functions and other functions. Finally, some guards were considered hazardous in themselves due to sharp edges or corners.

The German study (Apfeld et al, 2006; Luken et al, 2006) also highlighted the importance of **ergonomic factors** in relation to the use of machinery safety devices. In many cases the interface between worker, machine and protective device was not considered to be user friendly or ergonomically designed (e.g. the application of several protective devices had reduced the workspace available). In the case of machining centres, safety devices were bypassed because of limited visibility due to protective devices, whereas in the case of CNC milling machines/lathes, protective devices were tampered with because they slowed down the working process. Consequently, behaviour related to convenience. For example, tampering was viewed as a requirement to be able to work due to the poor ergonomic design of the machine/protective device. By tampering with safety devices, respondents reported being able to observe the working process clearly; tampering improved visibility. Tampering was also considered to provide a more effective way of dealing with faults and helped operators to achieve a quicker installation process. In addition, tampering behaviours were easy to carry out and required little effort (i.e. taking an average of 12 minutes to tamper with a safety device). In many cases, machines were delivered from manufacturers with tools to carry out the tampering, meaning that operators need not be 'creative' or 'resourceful' when carrying out tampering activities.

Samant et al (2006) found that **adequate machine guarding** was **not available for many machines**. This finding lends weight to the view of several papers that argued for the importance of considering machine safety, particularly safeguards early on in the design and production stages. Freedman (2004) argued that designers frequently think only of production processes, ignoring the fact that the system will be safeguarded later to prevent injury. The result is that operatives often find safeguards inhibit their ability to perform their task efficiently, reducing productivity. Many operators therefore are motivated to bypass safeguards to keep a sustained production pace or to troubleshoot equipment. Dzwiarek's (2004) analysis of accidents concluded that in order for the safe behaviour to be facilitated, machine control systems should be designed in such a way to prevent incorrect operation of the machine by workers.

Sherrard (2007) suggested that **poor machine maintenance** is an influence upon behaviour, and that infrequently used machines are often overlooked in maintenance schedules. Indeed poor maintenance procedures were identified as an influencing factor in the fatal accident investigation (reported in the Department of Health State of New York case report, 2004). McConnell (2004) described the development of a machine safety programme and discussed reasons for non-compliance. One reason was the practice of maintenance staff removing or disabling safeguards. Operators then subsequently run the machines without the safeguards being reinstated. Roudebush (2005) echoes this point. This article discussed risk assessments for machine safety and specifically noted the importance of ensuring that safeguards are restored (if they need to be removed/disabled to carry out tasks, conduct maintenance) before equipment is operated.

Finally, the importance of **legislation and clear standards for machine safety** emerged as an enabling factor. Chinniah (2009) reported that Quebec's Occupational Health and Safety regulations describe general aspects of machine safety (use of guards etc), yet do not refer to any international or Canadian safety standards. No certification of dangerous machines is required unlike Europe where the Machine Directive prevails. The majority of machines in Quebec are imported and the use of Canadian or international safety standards by individuals, employers or engineers when upgrading existing machines is challenging. When designing their intervention to improve machine safety, Brosseau et al. (2007) examined the guidance and information available to companies/owners. The authors concluded that standards could be complex and difficult to understand and interpret for owners. There is often limited access to external advice, and few companies were found to seek input from safety experts. Additionally, business and trade associations were not felt to provide sufficient information or resources for machine safety.

3.1.3.3 Reinforcing factors

A variety of reinforcing factors emerged from the literature. The article providing advice for safety leaders on how to implement lock/tag out programs (Elliot, 2003) did not discuss factors influencing behaviour directly. However reinforcing factors can be implied from the suggestions made. These included the need for a **healthy organisational culture** with a **good safety management system**, **good communication and management support**. This view was echoed in many of the papers, for example Sherrard (2007) argued that the lack of a healthy safety culture would reinforce unsafe behaviour. Poor management influence, poor safety culture and a **lack of enforcement** was claimed to support worker violation of machinery rules such as the removal of out of service signs (Sherrard, 2007). In the papers related to the metalworking shop study (Samant et al, 2006, Brosseau et al, 2007; Parker et al, 2009), size of business was related to operative behaviour. Larger businesses were found to be more likely to have an effective safety infrastructure and safety climate reinforcing safe behaviours. The investigation of a fatal accident report (Department of Health State of New York, 2004) also identified culture of the organisation as an influencing factor. The evidence suggested a lack of enforcement of the rules and a culture in which violation was accepted. Many employees reported using and observing the machine involved in the incident working with the safety gate open, suggesting that it may have been the norm to violate safe practice in that organisation.

McConnell (2004) discussed the development of a successful machine-safeguarding programme, outlining requirements of a successful programme and reasons for non-compliance. A reinforcing factor associated with non-compliance/overriding safeguards implied by the author was a **lack of management commitment** to health and safety and a belief by employees that management encourage overriding safeguards; **employees perceive management pressure to override safeguards** in order to meet production goals. Even if management are committed to health and safety, enforcement can be difficult. Apfeld et al (2006) found that it is not always possible to identify (visibly detect) when protective devices have been tampered with. **Tampering can be easily and quickly reversed** (e.g. in the event of internal/external checks) making it difficult for supervisors/managers to identify if non-compliance has previously occurred and devices have been manipulated.

Apfeld et al (2006) found little or no integration of the problem of the defeating of interlocks into safety culture. There appeared to be a social pressure for manipulating safety devices. Tampering behaviour appeared to be tolerated in organisations. Sixty percent of operators reported that tampering is tolerated, 14% reported that such behaviours were expected, and 10% reported that they experienced pressure by colleagues to bypass safety devices. In 30% of the cases investigated, tampering behaviours were carried out with another colleague. In many cases, negative consequences for the manipulator were missing (behaviour was tolerated by peers/managers). Combined with behaviour strengthening aspects (e.g. higher work pace) this supported manipulative actions.

This accepted behaviour means that there are no negative consequences in place to prevent these behaviours (i.e. in the form of reprimands); on the other hand, tampering with safety devices acted as positive reinforcement for operators as there were benefits associated with these behaviours including working faster, improving visibility, dealing with faults more efficiently and improving working and movement. The **presence of positive reinforcement and absence of negative consequences (punishment) when safety devices are tampered** means that tampering is more likely to occur. Perhaps unsurprisingly then, Apfeld et al (2006) reported that approximately 50% of operatives did not have a negative view towards tampering. Of these 50%, over half were unclear of the consequences of tampering (operational or legal consequences) whilst 5% were unaware of operating a machine that had been manipulated. In addition about a quarter of supervisors surveyed were also unclear about the legal consequences. Chinniah (2009) mirrored these findings, stating that reasons for bypassing safety devices included a lack of disciplinary action for those who bypass.

As a summary of the above, the PRECEDE model (Green, Kreuter, Deeds & Partridge, 1980) has been populated with the key factors influencing operator behaviour that emerged from the current literature review. This may be found in Appendix 3.

3.1.4 Suggestions from reviewed papers

Brosseau et al (2007) and Parker et al (2009) argue that any intervention to improve machine guarding compliance should be multifaceted i.e. address the context and environment, individual factors such as self-efficacy, and the reinforcement of behaviours. Interventions need to address knowledge of hazard identification and control, administrative procedures and training. Methods should be varied and include information transfer, role models, skill building, problem solving, goal setting, active learning, incentives, social support, guided practice and reinforcement. In line with this viewpoint, the current literature review identified multi-faceted suggestions to improve compliance in the use of interlocks/machine guards. Key suggestions are summarised in boxes 3-5 below (categorised as relevant to the individual, the organisation and the machine/guard design). A more detailed account of the suggestions identifying the source may be found in Appendix 4. Key suggestions specifically from Apfeld et al (2006) are contained within Appendix 2. It must be noted that the suggestions whilst including CNC machines also include other types and at this stage can only be regarded as an indication of areas to explore further in phase 2 of this research.

- Tailor interventions to target population (e.g. operator/manager). Each group should have specific performance objectives.
- Raise awareness of personal susceptibility. Ensure knowledge is relevant to hazard and control.
- Provide training/knowledge specific to different types of machine/processes and guards. Ensure sufficient time for training.
- Operator training in hazard identification and safe working procedures. Vary training methods to accommodate individual needs/learning style e.g. classroom, IT, and on the job training.
- Establish programmes of accountability so individuals believe the correct use of safeguards is their responsibility.
- Design safeguards to reduce the benefits for the individual of defeating them e.g. improve visibility by use of mirrored surfaces, increased light levels, improved viewing angles.
- Link negative consequences to tampering behaviour e.g. safety and legal consequences, and consistent enforcement by management. Send a clear message that tampering is never tolerated.

Box 3 Individual suggestions

- Ensure the development of a healthy safety culture - promoted at all levels within the organisation e.g. operators, supervisors and management to discourage tampering behaviours.
- Raise awareness of hazard amongst managers. Visible management commitment to machine safety.
- Rigorous safety management systems e.g. clear policies/procedures, training provision and accurate written records. Develop and implement written machine safety programmes to include standard operating procedures, emergency procedures, procedures for clearing jams, maintenance and reporting systems for malfunctions. Ensure that risk assessments take account of all operating modes and activities.
- Effective monitoring and enforcement to promote safe behaviour e.g. appropriate supervision and training. Line managers need to monitor performance to ensure that safeguards are used and to take corrective actions where non-compliance is observed.
- Effective worker involvement strategies e.g. involve operators with machine procurement and in the development of safe working procedures/policies.
- Occupational health and safety specialists and production specialists should be involved when planning and procuring machines.
- Training at a minimum should include: hazards associated with machine, how each safety device provides protection, standard safety procedures for removing jams, how to identify malfunctions of safety interlocks and what to do if a safety device is missing, damaged or malfunctioning.
- Use of safety representatives/committees to facilitate and drive improvements.

Box 4. **Organisational suggestions**

- Operating processes should be designed to take into account the use of protective devices. The selection of safety devices should be driven by their degree of appropriateness and **not** costs.

- Design machinery to make it hard for operators to manipulate safeguards e.g.
    - Use of fixed safeguards where possible.
    - Installation of interlocks between safeguards and equipments.
    - Sensors that send audible signal when a machine is operated without safeguards.

- Ensure that safeguards are restored (if removed/disabled to carry out tasks) before equipment is operated. Where safeguards have been removed/disabled, provide hazard-warning signage (signs, signal lights and awareness barriers).

- Designers should be well versed in the productivity enhancing side of safeguarding. Safeguards must be considered simultaneously with the systems design.

- Risk assessments should be performed during the design phase and prior to commissioning, to ensure that no new hazards have arisen in the integration of safeguards process.

- Safe Distance calculations should be made at the initial commissioning of the system and periodically thereafter to ensure that mechanic wear over time has not caused the hazards stopping time to increase, thereby increasing required safety distance.

- Design out characteristics of safeguards that are perceived as negative by operators. This may be achieved by a variety of design techniques e.g. making safeguards easy to see through/around, move or reach over. General suggestions included making guards easy to replace, reducing visual obstruction, preventing inadvertent trips of emergency stops, encouraging machine lockout and the use of embedded or tamper-proof interlocks.

- Tampering actions can be easily reversed making it difficult to identify when devices have been manipulated. Visual and functional checks should be carried out prior to initial start-up and release for production.

- Inspection checklists with specific instructions on how to perform safety device checks and maintenance should be developed. Results should be documented and maintained.

- Employers should follow manufacturers suggested schedule for maintenance. Manufacturers should ensure that operating manuals have clear guidelines relating to safety interlocks and their maintenance.

Box 5. Machine/guard design suggestions

3.1.5 Strengths and limitations of reviewed papers

The findings from this review need to be considered in the context of the strengths and limitations of the papers included. Approximately half of the articles (6/16) included in the review were published in practitioner/specialist publications. In many cases, these papers offered insights and suggestions from the authors' experiences. Not withstanding the value of these papers, however, they often lacked empirical evidence to support the claims made or suggestions offered (providing a strong justification for phase 2 of the current research). For instance, some papers provided suggestions on how to improve the design of safeguards but it was not possible to ascertain whether these suggestions were based on empirical evidence or the authors' own personal experience. No papers provided information on the prevalence of bypassing machine safety guards in the UK, although relevant information was available for other countries, i.e. Germany (Apfeld et al, 2006; Luken et al, 2006), the USA (Freedman, 2004), and Poland (Dzwiarek, 2004). Given the similarity in types of machines and operating modes used in these countries it is therefore reasonable to infer relevance for the UK. The Apfeld paper did include CNC machines.

Further, with the exception of Apfeld et al (2006) and Luken et al (2006), none of the papers specifically addressed the factors that influence behaviours and/or decisions to defeat safety interlocks on Computer Numerical Control (CNC) machines. **Therefore, whilst it may be reasonable to infer relevance, it is not possible to state definitively that the factors identified in this literature review influence operators' behaviour to defeat machine safeguards on CNC machines.** The same issue also applies to the studies that implemented and evaluated interventions in order to improve machine guarding practices and the management of machine-related hazards (Brosseau et al, 2007; Parker et al, 2009). Those studies explicitly excluded CNC machines due to their complexity; therefore, it is unclear whether similar interventions would be of relevance to these types of machines.

Several methodological limitations were identified in the papers. For example, the study reported by Brosseau et al, (2007) and Parker et al, (2009) lacked a truly random selection of metal shops. It also lacked a true control group. The study therefore cannot definitively claim that the measured changes resulted from the intervention alone. Finally, even though process measures were collected they did not enable identification of which aspects of the intervention programs were most important.

Strengths of papers included the use of checklists that covered the multifaceted internal and external influences upon behaviour to measure baseline and outcome, machine measures based on consensus standards and validated through inter rater reliablily (e.g. Samant et al., 2006; Brosseau et al., 2007; Parker et al., 2009).

Finally, despite their lack of direct relevance a strength of many of the papers stems from their multi-faceted approach to machine safety e.g. they highlight the importance of ensuring design issues are accounted for, and that individual (e.g. risk perception) and organisational (e.g. training, procedures) factors are considered. Many of the suggestins for machine safety are generic and can be applied to any type of machine and across industry.

3.2 STRAND 3: SECONDARY DATA ANALYSIS: QUALITATIVE

3.2.1 RIDDOR Data

3.2.1.1 Type and site of injury/activity

RIDDOR[30] data form a 4 year period (2007/08 to 2010/11) represented incidents that occurred across the UK (all FOD regions represented) in the following broad range of industries:

- Engineering;
- Publishing and printing;
- Textiles;
- Wood products;
- Food production;

[30] The limitations of using RIDDOR data must be noted. RIDDOR requires employers, self-employed people and people in control of premises to report and is therefore limited by underreporting. Furthermore the reporting method allows for a prose account of the incident to be included in the data. This may be completed by the injured person, a witness, or another employee at the organisation and is subject to tremendous variation in quality of information provided. Free text is not a reliable source to generate statistics and the RIDDOR should not be seen as representing the total number of incidents involving CNC machines in the UK within this time period.

- Motor vehicle;
- Transport equipment;
- Rubber and plastic products.

Unsurprisingly, fingers are the most common site of injuries sustained using unguarded CNC machines followed closely by injury to upper limbs and hands. The types of injury sustained showed a broader variation with fractures, lacerations and contusion occurring most frequently. Only one amputation was reported. Type and site of injury are summarised in Tables 2 and 3.

Table 2 Site of injury

Injury site	Number
Finger	10
Upper limb	6
Hand	2
Lower limb	1
Eye	1
Total	**20**

Table 3 Type of injury

Injury type	Number
Fracture	6
Laceration	3
Contusion	3
Burn	2
Superficial	2
Multiple	1
Strain	1
Dislocation	1
Amputation	1
Total	**20**

The majority of injured parties were engaged in production related tasks, although two incidents occurred during maintenance/repair work (summarised in Table 4).

Table 4 Type of activity at time of injury

Activity	*Number*
Production	16
Maintenance repair	2
No information	2
Total	**20**

Various types of machine were reported in the RIDDOR data, although some reports were restricted to generic descriptions such as "CNC machine". The different types of machines mentioned were:

- Test rig;
- Automatic book packaging machine;
- Dyeing machine;

- ILAPACK bagger;
- Handman filler and super clipper;
- Airset sand mixing machine;
- OV slicer (crosscut food slicer);
- Turning machine;
- Lathe;
- Cross cutter machine.

3.2.1.2 Predisposing, Enabling and Reinforcing Factors

The factor themes (predisposing, enabling and reinforcing) identified from the RIDDOR data are presented in Table 5.

Table 5 Factors influencing behaviour

Factor	Theme
Predisposing	Fatigue levels of injured person (IP)
	IP predisposed to physiological condition (shoulder injury)
	Experience levels of IP
	IP observed engaging in unsafe behaviour prior to incident
Enabling	Operator allowed access to safety software
	Irregular checking of safety systems
	Interlock can be overridden/guard defeated
	Machine breaking down, blocked, entangled
	Machine design does not have interlocks
	Human error
	Machine malfunction
Reinforcing	Disciplinary action post incident
	Safety culture/management commitment - remedial modification of machine post incident
	Safety culture/management commitment - changes to machine operating processes post incident

3.2.2 Coin data

3.2.2.1 Type and site of injury/activity

The COIN[31] data (HSE's inspection and enforcement database) analysed reflects incidents across all FOD regions with the exception of Wales. A 4 year period (2007/08 to 2010/11) was used. The vast majority of cases occurred in engineering, metalworking and manufacturing enterprises.

As with the RIDDOR data, the most common site of injury was fingers, hands and thumbs. However, the COIN data reflected a more serious set of incidents compared with the RIDDOR data, with two fatalities and five amputations (see Tables 6 and 7).

Table 6 Site of injury

[31] *It must be noted that the quality of data held on COIN data is acknowledged as being variable e.g. comments by inspectors can be disparate in nature e.g. one or two short sentences to very detailed summaries.*

Injury site	Number
Finger	9
Hand	4
Head	3
Thumb	1
No information	6
Total	**23**

Table 7 Type of injury

Injury type	Number
Amputation	5
Fatality	2
Fracture	2
Laceration	3
Bruising	2
Crush	1
No injury involved	1
No information	7
Total	**23**

Where it was possible to do so, the task/activity being undertaken at the time of injury was also recorded, the data being summarised in Table 8. The results highlighted production activities as the most frequently cited activity where injury occurred (for those cases where information was available).

Table 8 Type of activity at time of injury

Activity	Number
Production	6
Assisting trained operator in folding operation on CNC Press Brake	1
Attending breakdown	1
No information	15
Total	**23**

A wide variety of machine types were mentioned in the COIN reports. These were:

- Mazak Quick Turn 8 CNC lathe;
- CNC Roborough REH020 0070396 DL16918 hydraulic beading machine - hydraulic press;
- CNC machining centre;
- Correa A-30/630 CNC milling machine;
- CNC press brake;
- CNC lathe;
- CNC laser profiler machine;
- Large CNC machining centre;
- Sinico TR 60/4-2T CNC machining centre;
- Axel Laser cutting machine;
- Wood turning CNC lathe;
- Hit 80 CNC lathe;

- Z Bavelloni CNC stone cutting machine;
- Hyundai Quickturn QT 18N CNC lathe;
- HAAS CNC lathe;
- Rhodes Pierce-All Pulsar 8 CNC punch press;
- UDF CNC lathe;
- Maxica 590 CNC lathe;
- SCM Windor 100 CNC profiler;
- Multiax CNC 5 axis router;
- Soraluce CNC machining centre;

3.2.2.2 Predisposing, Enabling and Reinforcing Factors

As for RIDDOR, the COIN data included textual descriptions of the incidents along with relevant accompanying information. The factor themes (predisposing, enabling and reinforcing) identified from the RIDDOR data are presented in Table 9.

Table 9 Factors influencing behaviour

Factor	Theme
Predisposing	Supervisors/staff with more experience were more likely to disable interlock
	Knowledge - IP had limited or no training on machine
	Knowledge - IP had been provided with basic and advanced training
Enabling	IP having access to dangerous areas of the machine
	Requirement to gain access to dangerous areas of the machine to perform a specific task e.g. quality control, unblocking a machine
	The potential for a machine to be operated successfully with interlock defeated
	Pressures to complete jobs quickly
	The ease with which interlocks could be defeated
	Lack of adequate training/instruction
Reinforcing	Post event - Improvement notices or prohibition notices issued
	Production benefits e.g. producing work more quickly

3.2.3 Summary of findings

The outcome related factors for the RIDDOR and COIN data indicated similarities in terms of type and site of injury, and in relation to the kind of task involved, the most common being standard production related tasks. Typically, incidents involve injury to fingers/thumb, hands or head, with latter being typically less frequent albeit a more serious incident. A key difference between the two datasets appears to be that the COIN data also reflects a proportion of very serious incidents involving fatalities and amputations. The COIN incidents are more serious in nature probably because of the source of the data i.e. HSE Inspectors. With regard to the factors influencing behaviour, Table 10 illustrates the number of cases where a factor was identified as well as the number of factor occurrences across the data set (some cases contained more than one factor).

Table 10 Count of factors by number of cases and number of occurrences

Factor and Data Set	Number of cases where factor identified	Number of factor occurrences identified
Predisposing - RIDDOR	5	7
Predisposing - COIN	5	5
Enabling - RIDDOR	14	21
Enabling - COIN	11	42
Reinforcing - RIDDOR	5	8
Reinforcing - COIN	6	10

As can be seen in Table 10, the greatest numbers of factors identified were enabling factors. Caution must be applied, however, when interpreting this finding. The data set was small and cannot be regarded as representative of the wider population. Additionally, this is the report of a qualitative analysis technique; therefore no statistical importance can be attached to the quantification of these factors. COIN and RIDDOR data by their very nature focus on objective aspects of the environment (e.g. the provision of inappropriate machine/guards), as opposed to subjective elements (e.g. operatives attitudes and beliefs and anticipated consequences reinforcing behaviour). Therefore, it is possible that the greater frequency of enabling factors observed is an artefact of this feature of the data set employed.

Furthermore, we need to be aware of the nature and limitation of the COIN and RIDDOR data. RIDDOR requires employers, self-employed people and people in control of premises to report and is therefore limited by underreporting. Furthermore the reporting method allows for a prose account of the incident to be included in the data. This may be completed by the injured person, a witness, or another employee at the organisation and is subject to tremendous variation in quality of information provided. Regarding COIN, the quality of data held on COIN data is also acknowledged as being variable e.g. comments by inspectors can be disparate in nature e.g. one or two short sentences to very detailed summaries. Consequently RIDDOR and COIN data are only likely to capture a part of the picture relating to incidents and accidents.

Key factors influencing operator behaviour that emerged from the secondary data were consistent with factors identified from the literature. The PRECEDE model (Green, Kreuter, Deeds & Partridge, 1980) has been populated with these. This may be found in Appendix 3.

Predisposing factors: the data suggest that operators with more experience are more likely to defeat CNC machine interlocks. This makes intuitive sense given that more experienced personnel are likely to have a detailed knowledge of a machine's operating capabilities combined with high levels of confidence/capability. There is also evidence that other predisposing factors such as pre-accident physiological states (injured shoulder) and behaviour patterns (e.g. repeated violations) are also important as potential indicators. The evidence regarding levels of training as a predisposing factor are somewhat ambiguous in that the data include incidents where injured parties had been provided with varying levels of training.

Enabling factors: the data suggest that operators being allowed physical access to the potentially dangerous areas of a CNC machine, combined with a reason or motivation to so (e.g. to clear the machine of a blockage or breakdown, to check the quality of a piece of work, pressures to complete work as quickly as possible etc.) are important enabling factors. A further important enabling factor is the relative ease with which certain CNC machines can be operated productively with the interlock features in a defeated state.

Reinforcing factors: only three reinforcing factors were observed in the data i.e. the issue of notices by inspectors, disciplinary action against employees and the production benefits of enhanced or faster production. The latter appears to overlap with the enabling factor 'benefit of completing work quickly' discussed above. Issuing notices and disciplinary action were "after the event" punishments. Insufficient information was given, however, to determine their precise effect. For example, if HSE action had reinforced operative safe behaviour. The available data therefore provided limited insight into the role of reinforcing factors.

3.3 CONCLUSION OF RESULTS

The literature review and qualitative analysis of secondary data have provided valuable insights. Regarding the extent and prevalence of safety device manipulation, the findings suggest that bypassing safety devices is a widespread phenomenon across industry and machine type, with potentially serious consequences. Several types of machines and protective devices were identified as commonly being tampered with. Tampering activities included removing separated activators, and bypassing and/or dismantling switches. Tampering activities were reported as frequently observed during setting up and production modes. Troubleshooting was also identified as associated with the manipulation/defeating of safeguards. The research suggests that tampering behaviour appears to be tolerated in many organisations.

Three overarching factors were identified as influencing operative behaviour regarding the defeating of safety devices/interlocks (see Appendix 3). The factors appear to be relevant regardless of industry sector. Predisposing factors are characteristics of the individual that help or hinder the uptake of risk controls e.g. risk perception. Enabling factors are objective aspects of the environment/system that block or promote the uptake of risk controls e.g. machine design. Reinforcing factors are environmental features that reward or punish compliance-related behaviour e.g. improved productivity. The findings imply that all three factors are relevant to understanding operative behaviour.

4. ISSUES TO CONSIDER FOR PHASE 2

Inferences have been drawn from the available literature and secondary qualitative data as to why operatives defeat interlocks on CNC machines, the extent of this problem and the factors that influence such behaviour. Little research to date has examined the psychological, social, organisational and environmental influences relating to this issue. As such, this research aims to provide novel insights into the specific knowledge, attitudes, values, beliefs and perceptions that operatives hold about the use of CNC machines and interlocks, and how these interact with social/environmental influences to result in non-compliant behaviour (defeating/attempts to defeat interlocks). Suggestions are made below regarding specific areas to explore in phase 2, through the proposed methodology of management and supervisor interviews and operative focus groups.

4.1 EXTENT OF THE PROBLEM

In order to answer the research question 'what is the extent of the problem' phase 2 should:

- Determine if the evidence exists to answer this question conclusively. Phase 2 should ensure that a specific aim of this research, to determine the scale of the problem i.e. the prevalence of the issue of defeating interlocks, has been met. Whilst it is possible to gauge prevalence for other European countries and the USA from studies documented in the literature, this was not possible for the UK due to the scarcity of literature. HSE CSEAD statisticians have completed preliminary work on this question in Phase 1 and the qualitative analysis of secondary data has provided an indication of incidence. The research team should consider whether this work is sufficient or whether further work is needed to confidently conclude the incidence of this problem by the end of this research.
- Include engineering; plastics and woodworking industries to determine whether there are industry-specific issues that have not been identified through research to date.
- Explore why troubleshooting, production and maintenance activities appear to be more susceptible to the defeating of interlocks.

4.2 FACTORS INFLUENCING OPERATIVE BEHAVIOUR

The PRECEDE diagram (Appendix 3) contains a complete list of the factors found to influence behaviour in the literature and secondary data. The Predisposing, Enabling and Reinforcing factors identified as influencing operative behaviour regarding the defeating of safety devices/interlocks appear to be cross-cutting, i.e. relevant regardless of industry sector. Phase 2 should focus on exploring whether certain factors play a more prominent role in influencing operative behaviour compared with general health and safety management, and whether any new factors emerge. At present, the extent of influence on operative behaviour remains unclear. Specific implications for Phase 2 for all three overarching factors identified as influencing operative behaviour (predisposing, enabling and reinforcing) are detailed below.

4.2.1 Predisposing factors

- Managers and operators knowledge and appraisal of the risk and associated consequences emerged from the research as an important influence upon behaviour. Ignorance/complacency and lack of knowledge and understanding of the severity/likelihood of the consequences from defeating safety devices (by both managers and operatives) was identified as contributing to unsafe behaviour. Therefore, questions to explore levels and accuracy of knowledge, as well as an apparent lack of acceptance of the risk of injury/fatality, and potential strategies to raise awareness of personal susceptibility should be included in phase 2.

- The current literature did not directly discuss risk perception/appraisal in the context of individual beliefs, values and self efficacy (an individuals belief in their ability to successfully perform a behaviour). However, many theories of behaviour change, e.g. Theory of Planned Behaviour (Azjen, 1985), have the view that an individual's beliefs, attitudes, values and self-efficacy influence their risk perception/appraisal and, subsequently, their behaviour. These factors relating to the individual need to be explored in the phase 2 question sets.

- It is important that phase 2 explores the attitudes, beliefs and values of individuals but also peer and management influence upon these (e.g. through an organisation's safety culture). Specifically, the attitude that productivity takes precedence over safety is important to explore, as this may be prominent in the sectors that are the focus of this research, and may in turn influence individual risk-taking behaviour.

4.2.2 Enabling factors

Phase 2 should explore all the enabling factors identified in the current research.

- Some enabling factors reflect financial and business concerns. For example, productivity pressures and the conflicting demands of production versus safety were highlighted as important influences. Interlocks/guards were felt to slow production or make equipment difficult to operate. Such influences and the associated cost-benefit appraisal processes should be explored in phase 2.

- The literature and secondary data suggest that the interface between worker, machine and protective device is often not user-friendly/ergonomically designed. Important enabling factors were identified as operators being allowed physical access to potentially dangerous areas of a CNC machine, combined with a reason/motivation to do so (e.g. to clear a blockage, to maintain machines, to visibly check the quality of work, to complete work as quickly as possible). A further factor identified was the relative ease with which certain CNC machines can be operated with the interlock features in a defeated state, coupled with the fact that routine maintenance usually requires guards to be defeated. Questions should therefore be included on the provision, accessibility, and functionality of machines and guards. Another area to be explored is ways in which machine design and production can be improved to take account of ergonomic issues and to design out characteristics of safeguards that are perceived as negative by workers e.g. poor visibility, slow production.

- A lack of, or inappropriate, supervision and training on the different types of machines, processes and guards that supervisors and operatives use was highlighted as an important factor. Lack of appropriate training and competence will have implications for self-effectiveness, and for beliefs about control (i.e. an operative's belief in their ability to control the risk successfully). Phase 2 should seek to identify what specific training is currently lacking and would be needed for safe practice, e.g. how to clear jams, operating procedures in an emergency.

- The literature also noted that standards/guidance could be complex and difficult to understand. Participant's opinions on the current standards and guidance should therefore be examined in the question sets, as well as the potential requirement for guidance targeted to specific audience groups e.g. operatives, supervisors and managers.

- The importance of worker involvement for good health and safety performance is well documented in the literature. Phase 2 should seek to explore current levels of worker involvement in machine safety within the identified industries as well as pragmatic solutions to improve this if necessary.

4.2.3 Reinforcing factors

- The literature suggests that there is little or no integration of the problem of defeating interlocks into the safety culture of organisations. There also appeared to be a social pressure for manipulating safety devices, and tampering behaviour appeared to be tolerated. Phase 2 should therefore explore levels of safety culture maturity and solutions as to how machine safety can be integrated more effectively into an organisation's safety culture.

- Lack of management commitment to health and safety, and a belief by employees that management encourage overriding safeguards to meet production goals emerged as a reinforcing factor. Even if management are committed to health and safety, enforcement can be difficult. The literature highlighted that it is not always possible to see when protective devices have been tampered with. Phase 2 should explore management commitment (both directly by questioning managers and supervisors in addition to seeking operatives' opinions of management commitment). Additionally, possible solutions and suggestions to aid detection of violations should be sought within the question set.

- Phase 2 should explore managers, supervisors and operatives' attitudes to the defeat of interlocks, and their beliefs and understanding of the negative consequences that could follow such behaviour. Ways in which these negative consequences can be accepted as likely to occur should also be explored. This is supported by the literature findings; operatives and supervisors did not have a negative view towards tampering and many were unclear of the operational or legal consequences of tampering. Combined with behaviour-strengthening aspects (e.g. higher pace of work), this supports manipulative actions.

- Finally, questions should seek to identify appropriate and meaningful positive reinforcements for managers, supervisors and operatives, e.g. making the safe way of working acceptable, convenient, and time-productive. In this way positive reinforcement will encourage and support the safe, rather than the unsafe, way of working.

4.3 SUGGESTIONS TO PROMOTE MACHINE SAFETY

The literature identified suggestions for improving health and safety performance in machine safety. Phase 2 should seek to examine managers, supervisors and operatives' views on the feasibility and practicality of such suggestions, as well as suggesting pragmatic and cost-effective solutions specifically for the issue of operatives defeating interlocks provided to CNC machines.

4.4 NEXT STEPS

Following delivery of this report, a breakpoint meeting with HSE customers will assist in finalising the areas of questioning for phase 2 of this research. The interview and focus group question sets will target the key areas that have emerged from this preliminary research to allow adequate coverage for probing important areas. Allowing scope to reveal any unknown influencing factors and exploring the feasibility and practicalities of possible solutions identified in the literature, are also important.

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6. APPENDICES

6.1 APPENDIX 1. SEARCH TERMS AND DATABASES

6.1.1 Literature search

HSE Information Services (IS) team were asked to search for all relevant literature dating back ten years. Prior to commencing the literature search a telephone meeting was held between the lead researcher and the IS team member conducting the search. This meeting provided the IS team member with sufficient background on the research and the research questions, and ensured that they were fully briefed to carry out a comprehensive search. During this meeting a list of search terms and associated databases to be searched was jointly developed. These are detailed below (terminology and search terms covered all spelling variations and year ranges).

Search terms:

- Safety device(s) or safety system(s)
- Guard*
- Interlock* or lock* or safeguard* or tag
- Defeat* or override or bypass*
- Over riding of interlocks
- Violate*
- Comply/compliance/complies
- Attitude*
- Behavioural violation*
- Machine(ry) guarding
- CNC or computer numeric control
- Manual machines
- Turning machines
- Machining centres
- Milling machines
- Lathes
- United Kingdom, Great Britain
- Europe, International

Databases and information sources searched:

- HSELINE, RILOSH, OSHLINE, CISDOC, NIOSHTIC
- Psychinfo
- Healsafe
- ASSIA
- IBSS
- Ingenta connect
- Science Direct
- Web of Science
- Ergonomics Abstracts
- Newspapers
- Trade papers

6.1.2 Secondary data analysis: qualitative

HSL collected qualitative elements of the secondary data (COIN and RIDDOR) generated by HSE CSEAD (i.e. text/comments written in the COIN incident/enforcement database and RIDDOR reports). Search terms used by CSEAD to identify relevant cases for each database were:

RIDDOR database

The RIDDOR database was searched employing two separate search strategies:

- To identify injuries to employees involving machinery, and where the notifier comments indicated that guards/interlock mechanisms had been disabled. Searches were conducted using the terms "CNC machinery" and "disabling of lock" for the period 2005/06 to 2009/10.

- To identify cases where the notifier mentions "disabling machinery" (not necessarily known whether CNC or not) or "CNC" with a mention of "interlocks".

COIN database

The COIN database was searched using the following keyword terms:

"*CNC*" - OR - "*Computer Numeric*" - AND - "*Disabl*" - OR - "*Defeat*"
- AND - "*Lock*" - OR - "*Guard*"

6.2 APPENDIX 2. SUMMARY OF PAPER - BYPASSING OF PROTECTIVE DEVICES ON MACHINERY (APFELD ET AL., 2006)

Given the direct relevance of Apfeld et al's (2006) research to the current project (research based on the manipulation and tampering of safety devices of machinery, including CNC machines in metal working companies) a more detailed summary of this paper than is possible within the constraints of the current literature review is warranted. This summary is provided below.

6.2.1 Aim of paper

The aim of this study was to examine the extent of manipulation and tampering of safety devices in metal working companies within Germany and to identify the reasons why these manipulations take place.

6.2.2 Methodology

Two surveys were carried out.

Survey 1 (General survey) aimed to obtain statistics on the extent of the problem by assessing estimations and how often manipulations happen, frequency of manipulations depending on the type of safeguard and operational mode. The survey was distributed to 1,000 health and safety experts (technical advisory staff and safety engineers). N = 940 valid responses were received. 65% of responses were from supervisory personnel or practitioners for occupational health and safety (Health and Safety experts). The remaining 35% were from training course participants or managers from the operational area.

Survey 2 (Special survey) aimed to obtain information about the types of manipulations observed in the field. A total of 202 manipulations were analysed focusing on:

- Type of machine.
- Type of safety guard.
- Type of manipulation that took place.
- Hazard appraisal.
- Mode of operation.
- Ergonomic aspects of the man-machine interface.
- Aspects at operational level.
- Aspects related to operators' personality.

N = 202 survey responses from:

- Staff of the BGMS (Company Health Management System).
- Staff of the MMBG (Mechanical Engineering and Metal Working Professional Association).
- Prevention service of the NMBG (North German Metal-Working Professional Association).

71% of the data was derived from small and medium-sized enterprises (fewer than 250 employees).

6.2.3 Results

6.2.3.1 Survey 1(General survey)

Extent of the problem

Results from survey 1 showed that approximately 1 in 3 safety devices are manipulated (temporarily or constantly). Specifically, 37% of machines were constantly or temporarily tampered with. In approximately half of the cases involving tampering of safety devices accidents can result representing approximately a quarter of all occupational accidents (according to survey respondents). It was further revealed that tampering with machines or safety devices was tolerated in one third of the companies surveyed.

According to the survey respondents, separating protective devices as well as protective device lockings are tampered most frequently. This was not the case with contact-free protective devices, such as laser scanners or light grids.

Reasons behind tampering

Survey respondents were asked about the reasons for tampering with safety devices. The reasons given included:

- Gaining time (22% of respondents)
- Time pressure/pressure on performance (14%)
- Raising productivity (7%)

Other issues identified related to 'convenience' e.g. simplifying work (N=122 respondents) and poor ergonomics of the machine/protective device (N=177 respondents).

The authors concluded that factors relating to increasing productivity (given time pressures) and improving the working situation were important factors affecting operators' tampering with safety devices. Additionally the survey found that the majority of operators underestimated the hazards associated with the tampering of safety devices.

6.2.3.2 Survey 2 (Special survey)

The second survey focused on a detailed analysis of specific instances of tampering observed in plants based upon an investigation of 202 machines. The findings showed that:

Types of machines

The majority of machines tampered with consisted of machining centres, presses and CNC milling machines and lathes. As the authors had suggested, it was not the case that older machines were more likely to be tampered with. 58% of the machines had been constructed post 1995 suggesting that newer machines are as likely to be tampered with.

Types of protective devices tampered with

The findings were consistent with the general survey (survey 1) results showing that electromechanical position switches often in combination with separating protective devices were more likely to be manipulated. Movable separating devices with position switch or locking (54%) and mechanical, non-moving separating protective devices (35%) are most prone to tampering.

Types of tampering

Tampering activities typically included removing and/or inserting separated activators, and bypassing and/or dismantling switches. Electromechanical position switches often in combination with separating protective devices were more likely to be manipulated.

Consequences of tampering

Approximately 1 in 3 (i.e. 37%) safety devices are manipulated (temporarily or constantly). In approximately half of these cases, survey respondents reported that tampering of safety devices could result in accidents; specifically, 27 accidents and 13 near misses reportedly occurred on machines that were tampered. However, it was noted that the occurrence of accidents and near misses cannot be solely attributed to the tampering of safety devices.

Modes of operation

Tampering activities are most frequently observed during automatic and installing/setting up modes (19.7%) followed by programming, program testing and test runs (10.7%) and re-adjusting modes e.g. converting, mounting and changing tools (5.3%). Troubleshooting was also identified as an activity associated with manipulation/defeating of safeguards.

Features of manufacturers

In 19 cases the manufacturers had pointed out how tampering could be carried out and in 10/19 cases they had provided the 'tool for tampering' i.e. a clamp, wrench or code.

Ergonomic aspects

Protective devices in some cases restrict visibility of the work process or tool, which can slow down productivity. The results also revealed that approximately 10% (23) of safety devices were of a new type and required new procedures. Further, in 145 cases it was shown that protective devices could be easily bypassed (i.e. without any effort).

Features of companies

There was a lack of training and awareness regarding tampering of safety devices. Over 20% of operators had not received any instructions or training and in just under half of the companies surveyed (45%) tampering was not discussed. However, in more than half of the companies there were procedures or measures in place to deal with safety problems arising from bypassing protective devices. In over half the cases, operators' wishes were not considered in purchasing equipment. 60% of cases investigated show that tampering is tolerated in organisations and in 14% of the cases machine operators expected tampering.

Operators

Tampering behaviour appears to be tolerated in many organisations as reported by 37% of supervisory personnel and 33% of experts in occupational health and safety. On the whole, operators did not view the tampering of safety devices as hazardous. Over 80% of operators did not feel unsafe in operating a machine that had been manipulated and about 29% were willing to accept the risk of a potential accidents. A third of operators viewed protective devices as obstructions in carrying out the work and did not feel that they were necessary. Approximately 50% of operatives did not have a negative view towards tampering; of those, over half were unclear of the consequences of tampering (operational or legal consequences) whilst 5% were unaware of operating a machine that had been manipulated. When asked about the benefits of tampering, the following were reported:

- Working quicker and higher levels of productivity.
- Being able to observe the working process clearly (i.e. improves visibility).
- Seen as a requirement to be able to work.
- Tampering provides a more effective way of dealing with faults.
- Helps achieve a quicker installation process.

When asked about changes that could be made, the following suggestions were made:

- Improving visibility of the working process or equipment.
- Introducing a new operating mode.
- Improving the interface between person and machine.

In terms of operational measures that could be used to prevent tampering, the following were suggested by operators:

- Training.
- New procurement or converting the machine.
- Involvement of the operator in the new procurement procedure.

6.2.4 Perspectives on results

The authors offered four different perspectives on the results of their research in the paper. These were: Psychological, Ergonomic, Organisational and Technical. Brief summaries of these perspectives and their respective suggestions are provided below.

6.2.4.1 Psychological perspective

Tampering behaviour appeared to be tolerated in organisations as reported by 37% of supervisory personnel and 33% of experts in occupational health and safety. This means that there is no negative consequence taking place to prevent these behaviours (i.e. in the form of reprimands); on the other hand, tampering with safety devices acts as positive reinforcement for operators as there are benefits associated with these behaviours including working faster, improving visibility, dealing with faults more efficiently and improving working and movement. Working with safety devices was seen as having several disadvantages, including slowing down work, interrupting the actual working process and restricting visibility. In addition, 12% of respondents reported that using protective devices requires a re-learning of habits in carrying out the work activity. The presence of positive reinforcement and absence of negative consequences when safety devices are tampered means that tampering is more likely to occur. It is important for negative consequences to be linked with tampering behaviours that may include stressing the legal consequences of failing to use safety devices, close monitoring of breaches and threats of punishment.

In addition, tampering behaviours were easy to carry out and required little effort (i.e. taking an average of 12 minutes to tamper with a safety device). Tampering activities could also be reversed very quickly if needed (in the event of internal or external checks), which also added to the ease of tampering activities. In many cases, machines were delivered from manufacturers with tools to carry out the tampering, meaning that operators need not be ‘creative’ or ‘resourceful’ in carrying out tampering activities.

Furthermore, 58% of operators reported that the danger resulting from tampering was ‘low’ and ‘very low’; these responses are in sharp contrast with those of the supervisory personnel and health and safety specialists who rate the dangers as high or very high. Specifically, 121/178 operators rated the level of danger created by tampering as lower than supervisors and health and safety specialists. These results suggest that operators had a poor appreciation of the hazards associated with tampering of safety devices.

In summary, it appears that there are several positive reinforcers associated with tampering of safety devices, coupled with tolerance of risky behaviours by organisations (i.e. not reprimanding tampering behaviours) and perceptions by operators that tampering is not hazardous or will have no negative consequences.

Social pressure

60% of operators reported that tampering is tolerated and 14% of them reported that such behaviours are expected with another 10% reporting that they experienced pressure by colleagues to bypass safety devices. In 30% of the cases investigated, tampering behaviours were carried out with another colleague.

Training

Only 60% of operators had received any training whilst more than half were unaware of the consequences of tampering. The overwhelming majority of operators (94%) also reported dealing with faults by themselves although only 36% had received appropriate training to correct faults.

Suggestions

Technical

- Installing additional operating modes and simplifying the process for searching and dealing with faults.
- Improve user-friendliness to ensure that working activities are not hindered such as being able to observe the work process with the protective device activated. Similarly, it should not be possible to facilitate the work process with protective devices de-activated.
- Decrease the ease with which tampering can occur – ergonomic principles should be applied to improve the machine-operator interface; in some cases, separations between operator and machine should be removed for instance by installing protective devices that only operate in emergencies (i.e. light grids instead of protection grids).

Organisational

- Operators should be involved in ordering machines.
- Time should be allocated for operators if re-learning is required.
- Management should make it clear that tampering behaviours are not tolerated – any punishments or prohibitions should be consistently implemented.
- Provide training to increase awareness of hazards associated with tampering behaviours and legal consequences of such behaviours.
- Discussions should be held between organisations and manufacturers to find technical solutions to be able to work as quickly and conveniently without bypassing safety devices and manufacturers should be made aware of legal consequences.

6.2.4.2 Ergonomic perspective

The survey findings suggested that fixed or movable protective devices, combined with electromechanical or position switches were more likely to be tampered with. These types of devices were more prone to mechanical tampering with no prior knowledge required. One solution regarding the electromechanical position switches would be to ensure that tampering results in negative consequences that could not be reversed, such as to damage of the entire component.

Devices that are activated without contact, such as smart camera systems that distinguish human parts vs. tools or mechanical parts, can replace fixed separating protective devices. Such devices cannot be easily tampered with and do not disrupt the workflow as they only come into effect in emergencies. However, they are costly and would require resources from an organisation, which could be a barrier to implementation of such devices.

In terms of potential changes to the way machines or protective devices are constructed, there are no easy solutions that would be applicable to all types of machines. Visibility is an issue that needs to be considered at the design stage as poor visibility was a commonly reported factor for bypassing safety devices. It is important that visibility is improved through the protective device (i.e. a window) or by optically bypassing the protective device. It is important that an operator's field of vision is considered when fitting safety devices.

Suggestions

The authors provided specific suggestions for machine manufacturers that included the following:

- Protective devices should be considered at the construction phase of machines to ensure that they are user-friendly.
- Working/operating processes should be designed in such a way that they take into account the use of protective devices.
- The selection of safety devices should be driven by their degree of appropriateness and not by cost.

6.2.4.3 Organisational perspective

Survey results revealed a number of organisational issues with regards to bypassing safety devices, including:

Tolerance of tampering in organisations: one third of companies tolerated tampering of safety devices with this phenomenon being more pronounced in SMEs. Further, the majority of companies surveyed did not address tampering or take measures to address safety problems that may arise from bypassing safety devices.

Operators tended to underestimate the risks associated with bypassing safety devices, suggesting that they received inadequate training and information on this issue; in addition, more than 50% of operators were unclear about the operational and legal consequences of tampering and about a quarter of supervisors were also unclear about the legal consequences. Measures that focus on training provision and information/awareness of those issues was requested by a quarter of respondents surveyed.

It is not always possible to identify when protective devices have been tampered with (i.e. may be obvious to detect with a position switch but not when software has been changed). Also tampering actions can be easily reversed which also makes it difficult to identify when devices have been manipulated.

Sixty-nine percent of tampering is not reversed for automatic operations whilst only 18% of machines that are manipulated are reset to the safety mode in special operating modes. More than 50% of the machines tampered with were new (less than 10 years old) suggesting that newer machines fail to meet user/operator requirements. Approximately 50% of operators reported that they are not consulted when new machines are purchased.

Suggestions

The following suggestions were given to address the above issues:

- The issue of tampering should be incorporated into safety awareness training
- Operators, as well as occupational health and safety specialists and production specialists should be involved when planning and procuring machines
- Visual and functional checks should be carried out prior to initial start-up and release for production.
- Development of a good safety culture (promoted by both operators and supervisors) to discourage tampering behaviours.
- Top down evaluation of fault logs about cases of tampering and possible modifications.
- Improvement of operating design of machines.

6.2.4.4 Technical perspective

Results from the survey 2 (Special survey) showed that tampering occurs on the following machines:

- Machining centres
- CNC lathes and CNC milling machines
- Presses

Both surveys (general and special survey) showed that tampering occurs on the following types of protective devices:

- Movable separating devices with position switch or locking (54%)
- Mechanical, non-moving separating protective devices (35%)

Tampering occurred at the following machine modes (all part of an automatic operating mode):

- Automatic operation (19.5%)
- Re-adjusting and setting (9.1%)
- Dealing with faults in the work process (6.2%)
- Supply and export of material (5.8%)

Specifically, of the 202 machines surveyed, 100 were manipulated in automatic operating mode. In the case of machining centres, safety devices were bypassed because of limited visibility due to protective devices, whereas in the case of CNC milling machines/lathes, protective devices were tampered with because they slowed down the working process.

In addition, tampering occurred during the following activities:

- Installation and set-up (19.7%)
- Programming, program testing and test runs (10.7%)
- Converting, mounting and changing tools (5.3%)

Of the 202 machines, 82 were tampered during special operating modes – for machining centres, tampering was a result of poor visibility caused by the safety device whilst in the case of presses tampering occurred as safety device slowed down the working tempo.

Electromechanical position switches were one of the most common safety devices tampered with which included:
- Separated activator dismantled and inserted
- Bypassing of the switch through other objects
- Position switches dismantled
- Substitute activators inserted

<u>Suggestions</u>

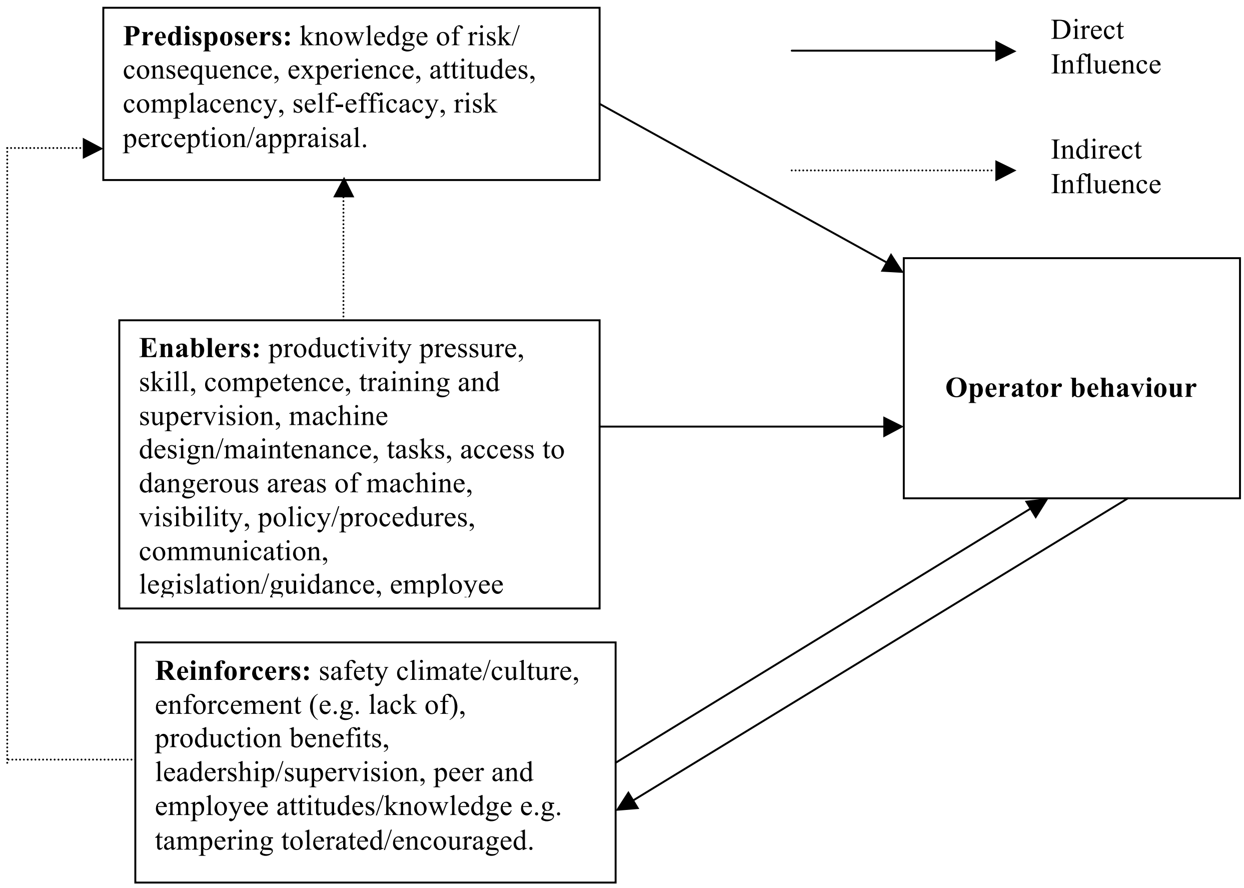
The authors suggested that tampering can only be prevented by ensuring that protective devices do not act as obstacles when operating machines. Technical suggestions to prevent tampering included:

- Use of storage of programmable controls (SPC) – software that interrupts the operation of a machine if unusual conditions are registered regarding the safety devices.

- Making it harder for operators to manipulate safety devices – technical solutions may include, attaching concealed mounted switches with coded mating components and tamper-proof fastening of protective devices (e.g. with one-way screws or connection means which cannot be unscrewed).

Finally, the authors argued that the most effective way of preventing tampering is through risk assessment and taking into account all operating modes and activities on a machine and incorporating those in the machine construction and manufacturing stages. It is also important for manufacturers of devices to supply necessary safety functions at reasonable prices and to point out how they can be used to prevent tampering.

6.3 APPENDIX 3. PRECEDE MODEL POPULATED WITH FINDINGS FROM CURRENT RESEARCH



6.4 APPENDIX 4. SUGGESTIONS FROM REVIEWED PAPERS

Brosseau et al (2007) and Parker et al (2009) argue that any interventions to improve machine guarding compliance should be multifaceted i.e. address the context and environment, individual factors such as self-efficacy, and the reinforcement of behaviours. Interventions need to address knowledge of hazard identification and control, administrative procedures and training. Methods should be varied and include information transfer, role models, skill building, problem solving, goal setting, active learning, incentives, social support, guided practice and reinforcement. In line with this viewpoint, the current literature review identified multi-faceted suggestions. These have been categorised as relevant to the individual, the organisation and the machine/guard design. Key suggestions from Apfeld et al (2006) are contained with the suggestions detailed below (see Appendix 2 for all suggestions).

Individual

At the individual level, Parker et al (2009) suggested tailoring interventions for target populations; training must be appropriate for the individual. Individuals must have the appropriate knowledge of the hazard and controls. Operators tend to underestimate the risks associated with bypassing safety devices suggesting that they receive inadequate training and information on this issue (Apfeld et al, 2006). Therefore, suggestions included the need to provide training and knowledge specific to the different types of machines, processes and guards that operatives are expected to use (e.g. Sherrard, 2007). Roudebush (2005) also suggested employee training in hazard identification and safe working procedures; training methods should be varied to accommodate individual needs and include formal classroom instruction, computer-based learning, on the job training and certification programs.

McConnell (2004) argues that individuals need to believe that the correct use of safeguards is their responsibility and suggest that companies establish a programme of accountability regarding the use of safeguards. Adams (2000) suggested that safeguards should be designed in a way to benefit the worker, thus reducing the perceived benefits for the individual of bypassing them. For instance, the use of mirrored surfaces on guards to improve visibility, increasing light levels at interest point and improving viewing angles. Finally, Apfeld et al (2006) reported that the presence of positive reinforcement and absence of negative consequences when safety devices are tampered means that tampering is more likely to occur. It is therefore suggested that negative consequences be linked with tampering behaviours. This could include stressing the legal consequences of failing to use safety devices, close monitoring of breaches, consistent enforcement. The authors suggest the provision of training to increase awareness of hazards associated with tampering behaviours and legal consequences of such behaviours. Sufficient time should be allocated for operators if re-learning is required. Management must make it clear that tampering behaviours are not tolerated and any punishments or prohibitions should be consistently implemented.

Organisational

At the organisational level Apfeld et al (2006) suggested the development of a good safety culture promoted by both operators and supervisors to discourage tampering behaviours. Similarly, Sherrard (2007) suggested the importance of good management and sound policy and Dzwiarek (2004) suggested that workers' incorrect behaviour should be addressed by appropriate supervision and training. McConnell (2004) stated that line managers need to monitor employees to ensure that safeguards are used and take corrective actions where non-compliance is observed. Apfeld et al (2006) suggested that one of the most effective way of preventing tampering is through risk assessment taking into account all operating modes and activities on a machine. The Department of Health State of New York (2004) suggested that employers should develop and implement a written machine safety program. This should include safe operating procedures, emergency procedures, procedures for clearing jams/maintenance, and reporting systems for malfunctions. Additionally, the report suggests that employers should provide training to ensure all employees know and understand the importance of safety features and standard operating procedures. Training at a minimum should include: hazards associated with machines, how each safety device provides protection, standard safety procedures for removing jams, how to identify malfunctions of safety interlocks and what to do if a safety device is missing, damaged or malfunctioning. Roudebush, (2005) discussed the importance of worker involvement, suggesting that safe working procedures should be developed in consultation with workers. These should be accompanied by positive safe behaviour reinforcement and supervision. Similarly, Apfeld et al (2006) suggested that operators, as well as occupational health and safety specialists and production specialists be involved when planning and procuring machines.

Samant et al, 2006; Brosseau et al, 2007; Parker et al, 2009 suggested the need for businesses to have clear policies and procedures, training provision and accurate written records. The authors comment that when designing interventions both owner/managers and employees should be targeted and each group should have specific performance objectives. Specifically, Parker et al (2009) reported that the addition of safety committees appeared to facilitate improvement. The biggest changes were seen in businesses that did not previously have safety committees. On the basis of these findings the authors argue that safety committees are an important component in improving machine safety in small businesses and should be put in place in those businesses that do not have one.

Machine/guard design

In terms of potential changes to the way machines or protective devices are constructed and applied, several suggestions emerged from the literature. However, it must be acknowledged that there are no easy solutions that would be applicable to all types of machines. In the context of the machine/environment, ensuring the correct use of guards at point of operation was considered crucial to prevent injury (Samant et al, 2006). Several suggestions were made and some of these are relevant for machine designers and manufacturers. Apfeld et al (2006) suggested that working/operating processes should be designed in such a way so that they take into account the use of protective devices, and the selection of safety devices should be driven by their degree of appropriateness and not costs.

McConnell (2004) made various design suggestions including the use of fixed safeguards where possible and the installation of interlocks between safeguards and equipment. The installation of sensors that send an audible signal when the machine is operated without safeguards was also suggested. Similarly, Roudebush (2005) discussed the importance of ensuring that safeguards are restored (if they need to be removed/disabled to carry out tasks) before equipment is operated. In instances where safeguards have been removed/disabled the need to provide hazard warning signage (signs, signal lights and awareness barriers) was emphasised.

Freedman (2004) suggested that safeguards must be considered simultaneously with the systems design. This will result in systems being designed that allow personnel to safely and easily perform their jobs with no need to bypass the safeguards. It was argued that system designers must understand the distance from a hazard that the safeguard must be mounted. Safe Distance calculations should be made at initial commissioning of the system and periodically thereafter to ensure that mechanical wear over time has not caused the ‘hazards stopping time’ to increase, thereby increasing required safety distance. Finally, risk assessments should be performed during the design phase and prior to commissioning to ensure that no new hazards have arisen in the integration of safeguards process. Designers should also be well versed in the productivity enhancing side of safeguarding. Dzwiarek, (2004) also suggested that systems should be designed in such a way to prevent incorrect operation of the machine by workers.

Adams (2000) suggested designing out characteristics of safeguards that are perceived as negative by workers. This may be achieved by applying a variety of design techniques that make safeguards easy to see through or around, move or reach over. General suggestions included making guards easy to replace, reducing visual obstruction, preventing inadvertent trips of emergency stops and encouraging machine lockout.

Apfeld et al (2006) suggested making it harder for operators to manipulate safety devices. Visibility was also cited as an issue that needs to be considered at the design stage. It is important that an operator's field of vision is considered when fitting safety devices and that visibility is improved through the protective device (i.e. a window) or by optically bypassing the protective device. It is not always possible to visibly detect when protective devices have been tampered with and tampering actions can be easily reversed making it difficult to identify when devices have been manipulated. Therefore the authors suggest that visual and functional checks should be carried out prior to initial start-up and release for production. The authors made further specific suggestions and full details may be found in Appendix 2.

With regards to maintenance, the Department of Health State of New York (2004) suggested that employers should inspect all machines periodically to ensure that all safety features are functioning properly. An inspection checklist with specific instruction on how to perform safety device checks should be developed, and results should be documented and maintained. Employers should follow manufacturers suggested schedule for maintenance and manufacturers should ensure that operating manuals have clear guidelines relating to safety interlocks. Finally, Chinniah (2009) suggested a need for more applied research on machine safety and the development of more reliable risk estimation tools.

6.5 APPENDIX 5. REPORT OF QUANTITATIVE ANALYSIS OF RIDDOR AND COIN DATA

6.5.1 Background

The defeating of interlocks on CNC, and other (manual) machines has been identified by HSE as a common problem in small and medium sized enterprises (SMEs). The risks from the defeating of interlocks are thought to be very high and there are examples of serious and even fatal accidents resulting from the defeat of interlocks on machines. This short report is part of a wider research project being carried out by the Health and Safety Laboratory (HSL) to identify and provide an analysis of the reasons, in terms of human factors, why operatives in engineering premises defeat, or are motivated to defeat or by-pass machinery guarding, particularly the safety interlocks provided to a variety of Computer Numerical Control (CNC) machines.

This short report outlines the findings from an analysis of the RIDDOR and COIN datasets to identify the number of incidents related to the defeat of interlocks. Specifically to answer the questions set out below;

1. How many health and safety incidents (accidents) (annually over a period of 3 years) are associated with the defeating of interlocks on CNC machines?
2. How many improvement notices (annually) does HSE issue relating to the defeat of interlocks?
3. How many prohibition notices (annually) does HSE conduct relating to the defeat of interlocks?
4. How many prosecutions (annually) does HSE issue relating to the defeat of interlocks?
5. How many complaints (annually) are made to HSE relating to the defeat of interlocks?
6. How many instances (annually) are there where inspectors have identified defeated interlocks on CNC machines (during the course of normal preventative inspection) but took no formal enforcement action?

6.5.2 Methodology

In order to be able to answer the research questions above a search and simple analysis of both the COIN and RIDDOR databases is required.

RIDDOR

Completed RIDDOR injury report forms (F5208s) include information such as the severity, nature, kind and circumstances of the injury. These reports are stored in HSE's RAID database. RAID holds injury reports for reported injuries, whether the industry in which they occur is enforced by HSE, HID or a local authority.

Unfortunately, no specific codes identify CNC machines or interlocks as agents of injury. However, injury reports include a free text field holding the notifier's comments. RAID doesn't hold information in the notifier's comments field for HSE-enforced fatal injuries. These comments are held in COIN.

A reported injury will appear only once in RAID.

In order to be able to identify relevant cases where an accident was associated with the defeating of an interlock the database would need to be filtered. Criteria to filter the data were decided in conjunction with HSE experts. The text box below shows the criteria used to search the text in the notifier's comments field in the RAID database criteria:

Box one

1. ("***cnc*" - OR - "*computer numeric*")**
- AND -
2. ("*disabl*" - OR - "*defeat*")
- AND -
3. ("*lock*" - OR - "*guard*")

Cases had to have at least one of the terms from each of the lines in the box above. For example if a report had 'computer numeric', 'defeat' and 'lock' in the text it would be included.

COIN

HSE also maintains an operational database (COIN) that holds records of enforcement activity and HSE inspectors' reports on incidents and inspections. The same criteria (box one) were used as the basis for a search of COIN.

Each injury, visit, enforcement and/ or other incident is allocated a service order number/ case number that may be associated with several reports on COIN.

The COIN team carried out initial de-duplication. However, some cases and service orders still had more than one row of data on the spreadsheets. A HSE Statistician further reduced the COIN record numbers to leave one row of data per each unique Service Order or Case ID number. The numbers of improvement and prohibition notices have been derived from a count of each notice type mentioned in the text for the Service Orders.

A 4 year period (2007/08 to 2010/11p) was used so that there could be 3 years of RAID records (RAID data for 2010/11p is not yet available.)

6.5.3 Results

The table below shows the results of the search. This table corresponds to the research questions identified above.

	2007/2008	2008/2009	2009/2010	2010/2011	Annual average
1. RIDDOR Accidents:					
identifiable from COIN using text	3	2	5	1	3
identifiable from RIDDOR database using text - closest matches	4	5	6	n/a	5
Count of service orders involving Improvement /prohibition notices	6	15	21	7	12
2 Improvement Notices	2	11	24	3	10
3 Prohibition notices	12	14	23	9	15
4 Prosecutions	-	-	-	2	-
5 Complaints	1	3	3	3	3
6. Other: Inspector visits /Advice education	6	4	1	5	4

6.5.4 Conclusions

This short report gives a summary of the analysis carried out to identify the scale of reported accidents and of HSE's inspection activity related to the defeating of interlocks on CNC machines. It should be noted that this does not help us to identify the scale of the problem regarding the defeating of interlocks on CNC machines; specifically we can not draw any inferences to the number of incidents where a CNC machine has been defeated nationally.

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HSE

Health and Safety Executive

Identifying the human factors associated with the defeating of interlocks on Computer Numerical Control (CNC) machines

HSL were commissioned by HSE to carry out research which sought to identify reasons why operatives defeat interlocks on Computer Numerical Control (CNC) machines, and to obtain an understanding of the extent of this behaviour across the UK engineering industry. The findings from this research provided a number of valuable insights about the frequency of defeating interlocks and the influences upon this behaviour.

With regard to frequency of defeating, semi-CNC machines were identified as being commonly defeated in the sample* used in this research. Common activities associated with defeating were setting, proving, swarf removal and deburring. Managers, and operatives / supervisors felt defeating was commonplace (the 'norm').

With regard to influences, three sets of influences on operative behaviour (Predisposing, Enabling and Reinforcing) were identified as influencing behaviour in relation to defeating interlocks.

Interventions that take into account these influences could be developed to promote behaviour change. Suggestions for such interventions are provided within this report.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

* It must be noted that these findings are taken from small-scale research and may not generalise to CNC machine users in the UK engineering industry.

RR974