Inadvertent operation of controls in excavator plant - insight, analysis and recommendations for prevention by design

Prepared by the Health and Safety Laboratory for the Health and Safety Executive 2014
There is extensive anecdotal information available, particularly from large construction contractors, which suggests that inadvertent operation of controls (IOOC) on excavators is a significant issue. Any inadvertent operation of excavator controls has the potential to cause serious injury or death; whether or not injury occurs is only a matter of chance.

This study was commissioned by HSE to gather evidence in the form of views, experiences and perceptions of both excavator operators, and subject matter experts working for both excavator manufacturers and for a major training provider. The aims of the research were to:

- Gain insight into the differing ways IOOC might occur;
- Identify the full range of control measures to prevent or mitigate the impact of IOOC; and
- Seek expert and end-user views on the likely efficacy of different design control measures.

The research identified that operators perceived IOOC as a problem and it was their view that IOOC risks could be reduced through improved excavator design and the introduction of new technology. They did not see usability, productivity and reliability issues as being barriers to introducing design and technical changes aimed at reducing IOOC risks.

Subject matter experts considered that more could be done to better manage the risks of IOOC using new technical solutions. Some manufacturer based subject matter experts associated the risk of IOCC with operator error and context of use, rather than being additionally linked to control and system design.

Manufacturers are possibly under-utilising the potential of technological, ergonomic and human factors expertise to address IOOC risks.

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.
Acknowledgements

The research team would like to thank all of the subject matter experts and their companies. We also extend our thanks to the excavator operators who participated in the study, and also the construction companies who provided access to the operators.
KEY MESSAGES

1. This was a qualitative study designed to discover the experiences and opinions of excavator operators and subject matter experts (manufacturers and trainers) with regard to inadvertent operation of controls (IOOC). As such, these opinions are not generalisable to the wider population of excavator operators but do provide a spectrum of opinion on IOOC causes and possible ways to reduce the risk.

2. Operators were asked how many times they accidentally operate their controls during a typical year. There was a large variation in the number of times that operators reported that IOCC occurred. Typical responses for those who reported IOOC were in the single figure range, although a small number of respondents reported higher numbers of incidents.

3. The majority of excavator operators interviewed regarded the risk of IOOC on excavators as either a problem or a serious problem. Most subject matter experts also viewed the underlying causes of IOOC as complex and multifaceted.

4. IOOC actions were attributed to both operator related reasons (e.g. operator body size, operator being distracted etc.) and ergonomic/design factors (e.g. small cab size, controls placed in less than optimum positions). Excavator operators reported that there is potential to reduce the risk of IOOC through machine re-design such as cab layout and size and the position/location of the safety lever.

5. From a list of potential control measures that could reduce the risk of IOOC, the following were most frequently selected by the interviewees:
   - Touch sensitive joy stick controls (the joystick will only be activated when it detects the presence of an operator's hand)
   - Seat switches (presence sensing Switch fitted under the operators seat)
   - Enable switches (a second switch has to be actuated after the safety lever has been lowered before the hydraulic controls become active)

6. Operators expressed the view that the introduction of such features, if well thought out and implemented, would not adversely impact on usability, convenience or productivity and a well-designed cab should enhance all of these.

7. Some operators agreed there is a risk that control measures could be defeated by operators. Therefore, any design and safety features aimed at minimising IOOC would need to be analysed to identify opportunities for violation and further measures introduced to reduce this additional risk e.g. software based technology.

8. Responses from subject matter experts suggest that the potential for change is under-realised by manufacturers, with the industry focusing on standard safety control measures (typically the access/egress safety lever).
EXECUTIVE SUMMARY

Background and rationale

Analysis of data collected through HSE internal databases (COIN and RIDDOR) revealed a significant number of incidents where serious injuries and fatalities have occurred by excavator operators inadvertently operating the controls (IOOC). In a five-year period to March 2010 there was one fatality and eleven major injury accidents involving IOOC. There is extensive anecdotal information available particularly from large construction contractors, which suggests that IOOC is a significant issue. Any inadvertent operation of excavator controls has the potential to cause serious injury or death; whether or not injury occurs is only a matter of chance. Official statistics will reveal only those which have led to injury but this report confirms there is strong evidence that inadvertent operation of controls occurs regularly.

This study was commissioned by HSE to gather evidence in the form of views, experiences and perceptions of both excavator operators, and subject matter experts working for both excavator manufacturers and for a major training provider. The study seeks to test a number of assumptions concerning IOOC, including:

- That IOOC is an important safety issue in the construction industry;
- That there are a number of viable and usable technical solutions in addition to the standard safety lever approach to IOOC prevention.

The aims of the research were to:

- Gain insight into the differing ways IOOC might occur;
- Identify the full range of control measures to prevent or mitigate the impact of IOOC and
- Seek expert and end-user views on the likely efficacy of different design control measures.

Methodology

The research was carried out using qualitative methodology that involved conducting semi-structured interviews with six subject matter experts (in the design and operation of excavators) and 30 excavator operators between June 2012 and February 2013.

A qualitative approach was used because it allows the possibility of in-depth explorations of the different aspects of a potentially complex topic such as IOOC. Semi-structured interviews allow the required scope and depth of exploration around the topic. However the conclusions cannot be generalised to the wider population of excavator operators or experts but this was not intended. This research was conducted to provide a spectrum of views and to identify consensus opinions to inform particular issues.

Access to the subject matter experts was obtained by requesting access to relevant personnel in UK based plant manufacturers and a national training organisation. Access to operators was obtained by approaching contacts in several small, medium and large construction and civil engineering companies. Both samples were opportunistic rather than purposive given the requirement that interviewees needed to be both willing and available to be interviewed. Although the sample of operators was opportunistic, it contained a good range of experience e.g. it had representatives from small, medium and large construction companies in different parts of UK, who were working on a range of construction projects.
Main Findings

The views from subject matter experts

The subject matter experts provided a comprehensive list of the different ways that they believed or knew from experience that IOOC could occur. These can be categorised into aspects pertaining to attention control; individual actions, individual physical characteristics/or clothing; and other:

1. **Attention control:**
   - Failing to put safety bars and safety controls in place
   - Talking to other people, i.e., labourer, foreman etc.

2. **Individual actions:**
   - Reaching for other controls
   - Operator turning around in the cab
   - Operator raising himself out of the seat
   - Pulling the left hand armrest/safety lever down with the joystick
   - Reaching out of the cab window and leaning into a joystick
   - Reaching for items in the cab inadvertently operating a control
   - Not operating the machine in the correct manner
   - Operator moving around in the cab while machine is running
   - Leaning out the side to do certain things
   - Operating the controls from the ground
   - Body parts touching the lever
   - Access/egress into the cab

3. **Individual physical characteristics or clothing:**
   - Body size
   - Clothes snagging the joystick

4. **Other:**
   - People riding on machines
   - Objects falling on the lever
   - Objects being pulled against the lever

The factors explaining IOOC as described by experts fall into ergonomic and design issues (e.g. the confined size of cabs, poor control system design) and operator related deficiencies (e.g. fatigue, being in a hurry, poor operator competence). Experts considered ergonomic and design issues were more likely to contribute to IOOC.

The subject matter experts provided a number of possible technological solutions that would help prevent IOOC or the consequences of IOCC. Possibilities included cameras (to help operators get better views outside the cab, particularly around common blind spots such as the boom obstruction to the right of the operator), proximity detection systems (similar to proximity parking sensors in cars that would help detect the presence of ground workers around the excavator) and seat sensors. Opinions about the practicalities of existing control measures aimed at preventing IOOC varied. These ranged from the view that existing control systems are “very practical”, to criticism of the deficiencies of specific safety system solutions such as seat...
switches and seatbelt switches. Subject matter experts thought that manufacturers did not see the potential for change because the industry is focusing on standard safety control measures (typically the access/egress safety lever) and this perhaps limited the introduction of new safety features.

The views from excavator operators

Excavator operators provided a range of explanations on how IOOC can occur. Their views were categorised as:

1. **Attention control:**
   - Forgetting control setting
   - Not paying attention
   - Talking with ground worker colleagues
   - Rushing

2. **Individual actions:**
   - Turning around in the cab
   - Leaning against the controls
   - Catching controls with his/her elbow
   - Moving the safety lever
   - Not engaging the safety lever
   - Not sitting in the seat
   - Operator moving from proper position holding the controls
   - Operating a wrong switch
   - Standing up doing deep drainage work
   - Getting into the cab

3. **Physical health**
   - Fatigue

4. **Individual physical characteristics and clothing type**
   - Loose clothing
   - Body size relative to cab size

It is worth noting that getting into/out of the cab and loose clothing accidentally moving control levers were the most frequently mentioned accidental actions by operators. IOOC can be attributed to operator related or ergonomic/design reasons, or both, but operators in particular were eager to suggest changes to the design of the machine to reduce the risk of IOOC, suggesting a perceived problem with current design.

A majority of operators agreed that IOOC issues could be eliminated, or the consequences reduced, through improved design of the excavator, outnumbering those that took the opposite view by approximately two to one. Their suggestions included:

- Better visibility out of the cab windows
- Replacing the safety lever with a delay timer switch (to supplement the safety lever so that when the safety lever is lowered there is a period of time before the hydraulics become active) and
- Re-designing the safety lever.
Operators thought that the most effective control measures for mitigation of the risks related to IOOC were touch sensitive joy sticks, enable switches and seat switches.

**Main Conclusions**

- Operators perceived IOOC as a problem;
- The operator view was that IOOC risk could be reduced through improved excavator design and the introduction of new technology;
- Subject matter experts thought that possibly more could be done to better manage the risks of IOOC using new technical solutions;
- Operators did not see usability, productivity and reliability issues as being barriers to introducing design and technical changes aimed at reducing IOOC risks;
- Some manufacturer based subject matter experts associated the risk of IOCC with operator error and context of use, rather than being additionally linked to control and system design;
- Manufacturers are possibly under-utilising the potential of technological, ergonomic and human factors expertise to address IOOC risks.
CONTENTS PAGE

1. INTRODUCTION ........................................................................................................1
  1.1 Background 1
  1.2 Aims of the research 2
  1.3 Objective 2

2. METHODOLOGY .......................................................................................................4
  2.1 The question sets 4
  2.2 The interviews 4
  2.3 Data analysis 5

3. RESULTS – SUBJECT MATTER EXPERTS ..............................................6
  3.1 Background information 6
  3.2 Perception of risks 7
  3.3 Inadvertent operation of controls (IOOC) 8
  3.4 The standardisation of excavator controls (for trainers and end users) 10
  3.5 Control measures that prevent or mitigate the consequences of IOOC 10

4. RESULTS – EXCAVATOR OPERATORS ..............................................14
  4.1 Background Information 14
  4.2 Perception of risks 14
  4.3 Operator’s Personal experiences of IOOC 17
  4.4 Eliminating IOOC issues through improved design – operator ideas and opinions 21

5. CONCLUSIONS ...................................................................................................23
  5.1 Subject matter expert interviews 23
  5.2 Operator interviews 24

6. GLOSSARY OF TERMS ...................................................................................25

7. APPENDIX 1: SCHEMATIC CAB DIAGRAM ..............................................26

8. APPENDIX 2: SUBJECT MATTER EXPERT INTERVIEWS
   QUESTION SET ..............................................................................................................27

9. APPENDIX 3: OPERATOR INTERVIEWS QUESTION SET 31
1. INTRODUCTION

1.1 BACKGROUND

Analysis of COIN and RIDDOR data (from the HSE’s database of reported accidents) has revealed a significant number of incidents where serious injuries and fatalities have occurred as a result of excavator operators inadvertently operating the controls. In a five-year period to March 2010 there was one fatality and eleven major injury accidents involving inadvertent operation of controls (IOOC). There is extensive anecdotal information available particularly from large construction contractors, which suggests that IOOC is a significant issue. The Machinery Directive\(^1\) requires manufacturers to design controls so that they cannot be unintentionally operated, however the accident statistics compiled by HSE suggest that inadvertent operation of controls is a clear and present risk to personnel working in the construction sector.

For the most part, manufacturers have focused on the risks associated with operators entering and exiting the cab. Excavators have therefore been fitted with a safety-locking lever that has to be raised to allow cab entry and exit. The safety-locking lever is interlocked with the main joystick controls and isolates these when it is raised. However incident analysis shows that there are two fundamental issues with this design. Firstly, the safety control lever is not always effective at preventing the inadvertent operation of controls and serious accidents have occurred where operators have intentionally or unintentionally lowered the lever at the same time as inadvertently operating a control. Secondly, the safety control lever does not prevent inadvertent operation when the driver is seated at the controls and incidents have occurred, for example, where the driver has leaned forward and his clothing has snagged the joystick.

The HSE and the construction industry recognise that IOOC is a problem. Groups representing end user interests in the UK (e.g. the Strategic Forum for Construction Plant Safety Group\(^2\)) have raised IOOC as a significant issue that needs to be addressed at the next revision of EN474\(^3\) and it is anticipated that the findings from this research will help in the development of the standard. Controls on excavators are now relatively standardized and even where it is recognized that control measures could be improved to reduce IOOC risks, manufacturers may be unlikely or willing to develop significant changes in design, unless such change is driven by both changes to the standard and pressure from regulatory authorities.

\(^1\) **DIRECTIVE 2006/42/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL**
of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast)

\(^2\) **In January 2009 Construction Plant Association formed a standing committee on plant safety, reporting to the Strategic Forum Health and Safety Group. The Health and Safety Group in turn reports directly to the Secretary of State for Work and Pensions, who has overall responsibility for all DWP activities, including health and safety and the HSE.**


British-Adopted European Standard.
1.2 AIMS OF THE RESEARCH

Through talking to a selected number of subject matter experts (e.g. employees of manufacturers, end-user construction organisations and trainers) and excavator operators, the research aimed to:

1. Gain insight into the differing ways IOOC might occur (e.g. contact with placed or dropped objects, clothing and parts of the body).

2. Identify the full range of control measures, as supplied, or retro-fitted (e.g. safety locking lever, seat sensors, seatbelt sensors) that are being used, or could be used (e.g. thermal joystick sensors, joystick hold to run buttons/levers, enable switches and/or time delays on the safety lever etc.) to either prevent the IOOC or reduce the risks associated with the IOOC.

3. Seek expert and end-user views on the likely efficacy of the different design control measures taking into account considerations such as usability, reliability, defeatability and anthropometrics.

The project was designed to be delivered in two stages:

- Stage 1: a set of semi-structured interviews with subject matter experts (manufacturers, trainers and an end-user construction organisation) and
- Stage 2: a set of semi-structured interviews with excavator operators.

1.3 OBJECTIVE

The main objective was to interview a sample of industry subject matter experts and excavator operators.

The subject matter expert interviews (comprising excavator trainers, control designers, and ergonomists) intended to:

- Identify the different ways in which IOOC might occur;
- Identify the various design control measures that could prevent or mitigate the consequences of IOOC; and
- Seek views regarding usability, reliability, defeatability and anthropometrics; and identify the best design control measures that could be carried forward to field trials (planned for the separate Phase 2 project).

The excavator operator interviews intended to:

- Identify perceptions of the major risks working with excavators;
- Identify operator perceptions of the different ways in which IOOC might occur;
- Explore operators’ personal experiences of IOOC;

---

*4 The measurement of the size and proportions of the human body, as well as parameters such as reach and visual range capabilities.*
• Explore operators’ perceptions of the various design control measures that could prevent or mitigate the consequences of IOOC; and
• Seek the views of operators regarding the usability, reliability, defeatability and anthropometrics of potential control measures;
• Seek the opinions of operators about the most effective control measures.
2. METHODOLOGY

The research was carried out using qualitative methodology that involved conducting semi-structured interviews with a range of subject matter experts (in the design and operation of excavators) and with a sample of excavator operators. A qualitative approach was proposed because it allows the possibility of in-depth explorations of the different aspects of a potentially complex topic such as IOOC. Whilst the findings provide an important insight into experts and excavator operators’ views within the sector, the conclusions cannot be generalised to the wider population of excavator operators or experts (this was not an intention of the research). The intention was to gather a range of views on how a particular problem was perceived and explained.

2.1 THE QUESTION SETS

The question sets for the semi-structured interviews (see Appendix 1 and Appendix 2) were designed in collaboration with the HSE research customer and the HSE Economic and Social Analysis Unit.

The subject matter expert question set was designed to gather information about:

- Background and experience of the respondents;
- How the respondents perceive risks related to IOOC in excavators;
- The different ways IOOC can occur;
- The standardisation of excavator controls;
- Control measures that prevent or mitigate the consequences of IOOC and
- The usability, reliability and defeatability of IOOC control measures.

The operator question set was designed to gather information about:

- Background and experience of the respondents;
- How the respondents perceive risks related to IOOC in excavators;
- Their personal experience of IOOC;
- The different ways IOOC can occur;
- Excavator design features and IOOC;
- Control measures that prevent or mitigate the consequences of IOOC and
- The usability, reliability and defeatability of IOOC control measures.
- Opinions about the most effective control measures.

Both question sets were designed to be comprehensive enough to cover a good range of issues relating to IOOC in excavators, while at the same time having the capability to explore topics in detail (through the use of optional probe questions) should the opportunity arise.

2.2 THE INTERVIEWS

2.2.1 Subject matter experts

Six interviews were conducted by the lead researcher, with a purposively selected sample of subject matter experts, comprising:

- Four interviews with engineers and designers working for excavator manufacturing companies with production operations in the UK;
• One interview with two trainers who have current experience of training new excavator operators on a range of commonly used models from a range of manufacturers;

• One interview with a health and safety professional working for a large UK construction company who has experience of investigating excavator accident incidents.

This range of experts was considered to offer a sufficient range of perspectives and expertise to offer a reasonable level of insight into the IOOC issue, while simultaneously offering the possibility to compare and contrast the feedback from people with different sets of experiences. The lead researcher, using contact information supplied by the HSE technical customer, recruited all interviewees after making contact either through telephone or e-mail.

2.2.2 Excavator operators

In total, 30 interviews were conducted with a sample of excavator operators drawn from a range of small, medium and large construction companies working at sites in various parts of the UK. Participating companies provided the lead researcher with access to operators involved with a range of construction projects, including housing developments, site clearance and transport related civil engineering. All interviews were conducted on site either in a suitable office or, for the smaller sites, in the staff canteen/mess room. The sample of operators (their experience on excavators and involvement in the industry ranged from four to forty years,) is considered varied enough to offer a reasonable level of insight into the IOOC issue.

All interviews were digitally recorded and professionally transcribed, the transcriptions being the basis for subsequent analysis.

2.3 DATA ANALYSIS

Each transcript was read in close conjunction with the question set. Relevant responses were highlighted, and copied into an Excel spread sheet on a question-by-question basis. The relevant responses were then interpreted by the lead researcher, with “key elements” identified and written down to provide, for each interview, a list of summarised points reflecting the “essence” of interviewee responses to the questions asked. The lead researcher interpreted the key elements pertaining to each question across all respondees and, where appropriate, drew conclusions based on these responses.
### 3. RESULTS – SUBJECT MATTER EXPERTS

#### 3.1 BACKGROUND INFORMATION

The questions in this section were intended to provide information about the job role and extent of experience of respondents. This information was used to help the researchers reach contextual judgements about the information provided to later questions. To help with interpretation of responses, a schematic diagram of a typical excavator cab is included as Appendix 1.

**3.1.1 Job roles**

The job roles of respondents are consistent with the primary function of their organisations. Table 1 summarises the scope of the six interviews undertaken.

**Table 1: Summary of respondents by organisation and job role**

<table>
<thead>
<tr>
<th>Type of organisation</th>
<th>Job roles</th>
<th>Number of interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavator manufacturer</td>
<td>Electrical engineer, mechanical engineer, design engineer, design manager</td>
<td>4</td>
</tr>
<tr>
<td>Operator training college</td>
<td>Senior plant instructor</td>
<td>1</td>
</tr>
<tr>
<td>Large construction company</td>
<td>Head of health and safety, environment and quality</td>
<td>1</td>
</tr>
</tbody>
</table>

The manufacturing based interviewees all hold technical roles, in contrast to the more “hands-on” experience of the other two interviewees. These differing sets of experiences suggest the possibility of different perspectives being aired in response to the questions, and indeed this is clearly reflected in differing sets of excavator related experience.

**3.1.2 Experience of excavator operation, control design and involvement in equipment trials**

The manufacturing company interviewees reported a range of experience in the operation of excavators, ranging from extensive operating experience and knowledge of excavators to limited hands-on experience and experience limited to specific types of machine e.g. mini excavators. The interviewee from the training organisation has, as would be expected, extensive experience of operating all types and sizes of excavator machinery, and also other types of heavy construction plant such as “dozers” and “dumpers”. The interviewee from the construction company had no operator experience on which to base his answers to the questions.

Only the respondent from the training establishment reported direct experience of IOOC incidents.

In terms of excavator control design, the manufacturing company interviewees reported having experience of control design, control system design and control placement decisions. One respondent reported experience of using ergonomic methods to achieve control integration. Two
of the manufacturing interviewees acknowledged that they had experience of equipment trials and trials of control design layouts.

3.1.3 Main factors influencing the adoption of excavator control design

Interviewees offered several explanations of the main factors influencing excavator control design. These were categorised as follows:

- Ergonomic and ease of use considerations (which were thought by one respondent to be becoming as, if not more important than, the standards that govern the industry);
- Market factors such as user expectations (some of which are fed back from user trials) and customer requirements for greater machine functionality which, in turn, serve as a driver for manufacturers to adopt a degree of consistency between their products;
- Industry standards such as EN 474-5 Earth – moving machinery – Safety – Part Five 5: Requirements for Hydraulic Excavators.

3.1.4 Deficiencies in current safeguarding measures

The manufacturing and trainer respondents reported that their role involves identifying deficiencies in safeguarding measures, mainly through undertaking risk assessments, but also through the use of ergonomic data (obtained using software packages such as Jack) and considering customer feedback.

The construction company interviewee reported identifying deficiencies as part of his accident investigation role.

3.2 PERCEPTION OF RISKS

3.2.1 Risks/hazards when working with excavators

Respondents mentioned a broad range of risks. These risks were categorised as follows:

- Machine centric risks (e.g. poor maintenance, poor visibility);
- The plant/people interface, most commonly bystander proximity to the machine when in use and;
- Context of use (e.g. the positive impact of a well-run site reduces risks and hazards).

Respondents based in manufacturing organisations mentioned all three types of risk/hazard. In contrast, respondents in the training and construction organisations focused almost exclusively on the risks generated by the plant/people interface.

3.2.2 Other risks and/or hazards

The risks associated with IOOC were mentioned and acknowledged by all respondents.

However, the perception of the level of risk associated with IOOC varied across the manufacturing company respondents. Some of this group perceived the risk from IOOC to be small or low (under the assumption that the machines are correctly operated), whereas others in this group acknowledged IOOC as a safety issue and hence saw IOOC as a significant risk. However, the manufacturing company respondents, regardless of their perception of IOOC risk, saw the operator as “the” significant causal factor in IOOC.
While also mentioning inappropriate operator use of the machines, the training establishment respondent also talked about aspects of machine design as contributory factors to IOCC. In addition to acknowledging that IOOC incidents are quite common events in the “real world”, the trainer respondent specifically mentioned the “auto idle feature” (incorporated as a fuel saving feature) as a design measure that could directly increase the degree of risk associated with IOOC (if a control is inadvertently actuated while the machine is on auto idle, the machine operating speed automatically jumps to a high number of engine revolutions, which can result in the rapid movement of the machine).

This respondent also mentioned other ways in which the risk of IOOC risks could be mitigated through the use of different system design principles e.g. touch sensitive controls that require the presence of a human hand. These differences in perspective between the experts could be important. Compared to the experts, the end-user respondents (operators) appeared to be more willing to acknowledge that IOOC risk could be addressed through changes to machine systems and design.

3.3 INADVERTENT OPERATION OF CONTROLS (IOOC)

3.3.1 The different ways that IOOC can occur

Respondents provided a list of ways that they knew or believed IOOC could occur, based on their experience and understanding. The typical layout of the controls on a tracked excavator is shown in Appendix 1.

Attention control:

- Failing to put safety bars and safety controls down in place
- Talking to other people, i.e. labourer, foreman etc.

Individual actions:

- Reaching for other controls
- Operator turning around in the cab
- Operator raising himself out of the seat
- Pulling the left hand armrest/safety lever down with the joystick
- Reaching out of the cab window and leaning into a joystick
- Reaching for items in the cab inadvertently operating things
- Not operating the machine in the correct manner
- Operator moving around in cab while machine is running
- Leaning out the side to do certain things
- Operating the controls from the ground
- Body parts touching the lever
- Access/egress into the cab

Individual physical characteristics or clothing:

- Large people
- Clothes snagging a joystick

Other:

- People riding on machines
• Objects falling on the lever
• Objects being pulled against the lever

3.3.2 The main factors that contribute to IOOC

The factors described by expert respondents fall into two main categories:
• Ergonomic and design issues (e.g. the confined size of cabs, poor control system design) and;
• Operator related deficiencies (e.g. fatigue, being in a hurry, low operator competence).

When asked specifically to comment on contributory factors to IOOC, and in contrast to their responses to previous questions, manufacturer respondents mentioned primarily design and control system issues (in addition to operator derived factors). This suggests that IOOC is a multifaceted issue that has roots in both equipment design and use.

3.3.3 Risk of inadvertent operation of controls and how often it occurs

The feedback from both manufacturer and trainer respondents is that IOOC on excavators is a significant and present risk. Although some respondents said that they were unaware of the frequency with which IOOC incidents occur, several thought that IOOC incidents were likely to occur more often than the official statistics suggest. Typical incidents are only reported if an accident results i.e. the inference is that the vast majority of IOOC incidents occur but do not result in injury, but have the potential to do so.

3.3.4 Particular situations in which people are more likely to inadvertently operate the controls

Respondents provided a very broad range of answers to this question. This observation suggests that IOOC could occur in a very wide range of circumstances. The most likely circumstance to result in IOOC was thought to be (by both experts and trainers) during access and egress from the cab.

3.3.5 Most common “inadvertent operation of controls” near misses

As with likely IOOC situations, respondents provided a spectrum of responses to this question ranging from clothes snagging controls to access and egress from the cab. However, an operator moving around in the cab was seen as the most likely cause of an IOOC near miss.

3.3.6 Factors affecting the difficulty of avoiding “inadvertent operation of controls”

Respondents thought it possible to reduce the likelihood of IOOC occurring, but that it would be very difficult to prevent them entirely. Manufacturer respondents cited small cab sizes, loose clothing and poorly designed safety systems as factors making it difficult to avoid IOOC incidents. Complementary to this, the respondent from the construction organisation saw potential in changing design factors to reduce the risk of IOOC incident occurrence, e.g. changing cab configuration and imposing a time delay before certain controls are allowed to become active.
3.4 THE STANDARDISATION OF EXCAVATOR CONTROLS (FOR TRAINERS AND END USERS)

3.4.1 Departures from the standard approach to control functions for new and legacy excavator models

The small “micro” excavators have non-standard control functions. Few older models of excavator are equipped with non-standard controls.

3.4.2 Non-standard controls as a significant contributory factor in IOOC incidents and near misses

Respondents thought that standard control layouts contributed to reducing the risk of IOOC occurring.

3.5 CONTROL MEASURES THAT PREVENT OR MITIGATE THE CONSEQUENCES OF IOOC

3.5.1 Assessing IOOC risks and familiarity with EN474-1

Respondents from both manufacturing companies reported that their organisations carry out formal risk assessments in relation to IOOC.

All respondents from both manufacturing organisations reported familiarity with EN474-1. However, there was not a consensus on the adequacy of EN474-1 in relation to IOOC. The EN474-1 standard was perceived by some respondents as adequate in the context of current legislation, but could be augmented or modified to take account of “real world processes and people” e.g. it could be improved so as to more adequately address the risks posed by IOOC.

3.5.2 Control measures on different sizes/makes and models of excavators

All respondents reported that control measures are similar, regardless of excavator size. The manufacturer respondents reported that control measures are broadly similar across different manufacturers of excavators.

3.5.3 Control measures used on other mobile plant (i.e. excluding excavators) to prevent inadvertent operation of controls

Respondents provided an array of possible technological solutions that would help prevent IOOC. Possibilities included cameras (to help operators get better views outside the cab, particularly around common blind spots such as the boom obstruction to the right of the operator), proximity detection systems (similar to proximity parking sensors in cars that would help detect the presence of ground workers around the excavator) and seat sensors. However respondents also provided additional information about the context and functionality that would be necessary in order for these systems to be effective:

- The controls should be easily isolated;
- Re-thinking standard control layouts;
- Introducing control systems that detect the presence of a human hand in order to become fully functional e.g. joystick energisation as an activation process;
- The requirement to operate two controls at the same time ) and
- Control safety systems that are not easily overridden.
In terms of other types of mobile plant, a number of features were mentioned by respondents that might be utilised to control IOOC risk in excavators. These features included the trigger levers installed in MEWPs, physical guards placed over the controls, seat sensors, control locks and heat sensors built into the hand controls of cranes.

3.5.4 Practicality of current control measures on excavators or other mobile plant

Opinions varied about the practicalities of existing control measures aimed at preventing IOOC, ranging from the view that existing control systems are “very practical” to criticism of the deficiencies of specific safety system solutions such as the seat switches and seatbelt switches typically used on dumper vehicles. One respondent thought that existing solutions were the “minimum that could be achieved” and another that existing systems “do not present a technological challenge as they are motivated by legislation”.

In terms of the practicalities of future effective measures, respondents suggested that these should, as a minimum, have the following features:

- They should not slow the operator down (otherwise they risk being defeated) and
- They should be as simple as possible.

3.5.5 Involvement in developing the control measures (manufacturers only)

Respondents from both manufacturing companies were involved in developing control measures.

3.5.6 Ease of avoidance of “inadvertent operation of controls”

Respondents offered a number of suggestions, including:

- Actively considering control placement in the design process;
- Prioritising the functional areas to define safety zones;
- Better understanding of operator and site personnel behaviour;
- A system for modifying the auto-idle feature so as to disconnect the hydraulics on transition to idle, employing a need to press the reset button to reinstate “On a 360 if you had the idle button on the lever……put the machine to idle and at the same time as putting it onto idle [that] disconnected …..the function of all the controls in the cab until you re-press that button to reset everything” and
- Additional safety measures such as time delays, interlocks and cab configuration.

3.5.7 Limitations regarding the implementation of other methods to prevent “inadvertent operation of controls”

Only respondents based in manufacturing companies offered suggestions as to the limitations of other IOOC methods. Suggestions included:

- Some approaches e.g. capacitative sensors restrict operator choice in use i.e. some operators may prefer to operate the controls using their fingertips rather than use their whole hands;
- The cost [of better safety] and customer expectations are potentially limiting factors
- MEWP style trigger controls are easily defeated and can lead to hand strain.
3.5.8 Effectiveness of the hardware control measures in place to avoid IIOC

Respondents gave contrasting answers to this question. One group said that existing hardware control measures were adequate and fit for purpose (all respondents in this group were drawn from manufacturers). In contrast, other respondents were more sceptical of the efficacy of existing hardware control measures, citing logic such as:

- Current control measures are not effective enough as there are still accidents;
- Existing control measures are very basic and do not really address the risks.

Crucially, in answer to the question about the potential for operators to bypass existing control measures, all respondents from the manufacturers acknowledged that it was possible for operators to bypass. Respondents thought that there were a number of reasons why operators would want to bypass safety systems, including:

- The need to maintain productivity;
- Convenience and comfort and
- Over-familiarity with the equipment.

3.5.9 Extent of ergonomics/human factors approaches employed

Responses suggest that ergonomic/human factor approaches have been underutilised as a means of improving control system design. Manufacturing company based respondents were of the view that ergonomic/human factor approaches are utilised, but only to a limited extent and have not been deployed to maximum potential. A non-manufacturer respondent was more critical on this issue, reporting that, from an ergonomics perspective, things “have not changed in 20 years”.

Only one of the two manufacturing organisations reported employing external ergonomics expertise (from universities).

3.5.10 Consideration of safety devices to prevent “inadvertent operation of controls” (For manufacturers only)

Responses to this question are summarized in Table 2:
Table 2 Manufacturer consideration of devices to prevent IOOC in excavators

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enable switches</td>
<td>Yes</td>
<td>Considered but haven't gone to the stage of any trials</td>
</tr>
<tr>
<td>Seat switches</td>
<td>Yes</td>
<td>Considered but haven't gone to the stage of any trials</td>
</tr>
<tr>
<td>Delay timers</td>
<td>Not sure</td>
<td>No</td>
</tr>
<tr>
<td>Dead man’s controls</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
4. RESULTS – EXCAVATOR OPERATORS

4.1 BACKGROUND INFORMATION

Although respondents all have direct experience of operating excavators, they hold a range of different jobs, some of which are management and supervisory roles. The sample thus draws upon a broad range of experience within the construction industry. To help with interpretation of responses, a schematic diagram of a typical excavator cab is included as Appendix 1.

Table 3 summarises respondent jobs as described:

<table>
<thead>
<tr>
<th>Range of jobs (as described)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge hand</td>
</tr>
<tr>
<td>Company Director and owner</td>
</tr>
<tr>
<td>Contract manager</td>
</tr>
<tr>
<td>Deputy assistant manager (Quarry)</td>
</tr>
<tr>
<td>Excavator operator</td>
</tr>
<tr>
<td>Excavator operator and ground worker</td>
</tr>
<tr>
<td>General Foreman Manager</td>
</tr>
<tr>
<td>Plant operator</td>
</tr>
<tr>
<td>Section foreman</td>
</tr>
<tr>
<td>Work superintendent</td>
</tr>
</tbody>
</table>

The average excavator operation experience time was 20.4 years, with a minimum of 1.5 and a maximum of 45 years. All respondents reported having experience in the operation of mini excavators, with a reported average experience time of 13.3 years. The average reported time since last attending a training course for operating excavators is 2.5 years.

All respondents reported being licenced through the CITB Construction Plant Competence Scheme (CPCS). Respondents are licenced to operate the following range of excavator types:

- 360 tracked (all weights)
- 360 tyred and tracked (all weights)
- 360 and 180 tyred and tracked (all weights)

Those licensed to operate 180 machines are in the minority (only four out of 30). Employing organisations tend to either own, or own and lease machines. Only one respondent reported being an owner operator.

Most respondents reported being aware of the risks related to IOOC.

4.2 PERCEPTION OF RISKS

4.2.1 Significance of the problem

In terms of perception of the risks, operator views were categorised as:

- IOOC seen as a problem or serious problem or
- IOOC not seen as a problem.
A majority of operators reported seeing IOOC as a problem, or serious problem. Some of those seeing IOOC as a problem reported either having personal IOOC experiences or knowing of the IOOC experiences of others:

“I’ve actually seen the damage it can do to someone, it’s not very nice to see”

“I’ve never actually had one but I have seen one”

Others seeing IOOC as an issue reported an appreciation of the risk potential:

“It can happen you know”

“It’s significant if there are people working close to the machine”

In contrast, respondents not seeing IOOC as a problem tended to explain their position either in terms of operator error or current safety design features:

“it’s just people not paying attention”

“It’s [the risk] quite low so it is because there is safety measures”

4.2.2 Perceived accidental actions resulting in IOOC

Respondents provided a list of ways that IOOC could occur, based on both direct and conceptual experience:

**Attention control**
- Fatigue
- Forgetting control settings e.g. whether a machine is set to track forwards or backwards
- Not paying attention

**Individual actions**
- Getting into the cab
- Getting out of the cab
- Turning around in the cab
- Leaning against the controls
- Catching controls with his/her elbow
- Moving the safety lever
- Not engaging the safety lever
- Leaning in the cab against controls
- Not sitting in the seat
- Talking with ground worker colleagues
- Operator moving from proper position holding the controls
- Operating a wrong switch
- Rushing
- Standing up doing deep drainage work
Individual physical characteristics or clothing:

- Loose clothing
- Large operator in a small cab

Getting into/out of the cab and loose clothing accidently moving control levers were the most frequently mentioned accidental actions.

4.2.3 Impact of excavator size on IOOC risk

Most respondents reported that the risks of IOOC are the same, regardless of the size of machine. Approximately one third of respondents thought that the risks are higher with smaller machines. Smaller excavators were thought more risky for the following reasons:

- Faster operating speeds
- Smaller cab size
- Operators getting in and out of the cab more frequently compared to larger machines
- Greater instability i.e. smaller machines “move about more”

4.2.4 Situations likely to result in near misses resulting from IOOC

The most common situations that operators believe are likely to result in near miss situations resulting from IOOC are:

- Buckets coming off
- Bucket or boom hits building or structure
- Bucket or boom hits ground worker
- Ground worker getting pinned under tracks
- Changing buckets
- Crushing ground workers in trench when working on deep drainage
- Lifting and placing objects using chains
- Dropping loads when performing lifting tasks
- Collisions with other plant e.g. dumpers

4.2.5 Impact of makes/models of excavator on preventing IOOC

Most respondents thought that excavator make and model had no impact on the risk of IOOC situations occurring. The prevailing view was that cab design and layout are very similar across makes and models, thus resulting in similar risk profiles regardless of machine.

In contrast to the majority of the sample, a handful of respondents thought that certain specific makes of machine were inherently less risky. For example:

- On machine A produced by manufacturer A - when the safety lever is actuated it isolates the hydraulics on every control, including the travel controls.
- On machine B produced by manufacturer B - machine has a second switch which isolates the hydraulics after a period of inactivity, even if the safety lever is down.
4.2.6 Ease of avoidance of IOOC

The operators supplied a range of ideas in answer to this question. It can be seen that most suggestions pertain to changes of the excavator design.

**Clothing**
- Avoid loose clothing
- No baggy clothes in the cab

**Attitude**
- Avoiding complacency

**Training**
- Better training

**Design**
- Space in the cab for storage
- Better visibility
- Changing position of the safety lever
- Enable switches/sensors
- Seat sensors
- Ground workers having a dead/kill switch
- Machine activation codes i.e. a security code (similar to a PIN) that the operator must input in order to activate the excavator
- Dead man’s switches
- Pressure switched on controls
- Redesign controls so they are an ergonomic distance from the operator
- Bigger cabs
- Warning buzzers
- Secondary switch to activate safety lever
- Shutting the machine down when operator leaves the cab
- Switch on controls
- Using the safety lever to isolate the controls
- Vicinity sensors

**Working procedures**
- Keep ground workers in designated work zone
- Toolbox talks

4.3 OPERATOR’S PERSONAL EXPERIENCES OF IOOC

4.3.1 Frequency of operators accidently operating controls

The operators were asked how often, on average, they accidently operated their excavator controls over a typical one-year period. Operators reported accidently operating controls between zero and 80 times a year, with zero or two accidental operations most common frequencies.

The research findings suggest that a proportion of respondents, for whatever reason, were reluctant to “admit” that they were involved in IOOC incidents. Furthermore, the large
difference between the lowest (0) and highest (80) suggests a high degree of variability in these estimates. A reluctance to admit to committing errors could be one explanation for this finding, as could genuine difficulties in making accurate estimates in an interview situation. It is likely, therefore, that these statistics offer an underestimate of the true occurrence rates of IOOC incidents.

4.3.2 Operator's personal experiences of IOOC situations

About half of operators reported that they had no recent personal experiences of IOOC incidents, suggesting the possibility of a reluctance to report experiences in an interview context.

The three most reported IOOC experiences are:

- Catching the safety lever in coat/clothing resulting in accidental slew
- Accidentally knocking control levers and moving the boom
- Turning around in the cab

The following selected quotes provide examples of IOOC experiences as described by participating operators:

“I’ve got up to say get me knife out my pocket and….. the coat has pushed the lever back down and the machine’s slewed and you think ‘****’ and it’s so easy done. I’ve done that a couple of times.”

“I turned to get a bag that was at the back of the seat, and I hit the lever and the bucket was on the ground but I still hit the lever and I felt the machine move and it was because the safety lever wasn’t up and I had turned around.”

“…..and as I got off the machine my coat got caught on the tracker lever which then started the tracks going and as I stood on the track my foot went in underneath the…yeah, and hence why I’ve got a problem with long coats.”

Operators reporting IOOC experiences were asked a follow-up question about whether the experience had changed the way they operate the machine. Most operators describing IOOC incidents reported that their experiences resulted in changed operating behaviour, in particular being more careful and having a greater awareness of precipitating factors (e.g. the impact of wearing loose clothing).

4.3.3 Excavator design features and IOOC

Operators reporting IOOC experiences were asked a follow-up question about whether the incident could have been prevented by a change in the design of the excavator. Respondents gave contrasting views as to whether design changes could have prevented IOOC incidents. The following selected quotes illustrate the type of design changes mentioned:

“…..because if that dead man lever cut out everything then it would have been okay.”

“….if the thing had been fitted in the seat at the time it would have been avoidable.”

“You would need to have a sensitive switch on the handle that recognised a hand, the technology you must be able to do that now.”
“Maybe if someone was leaving the seat that the hydraulics would switch off.”

“If that particular machine had had an isolator on the hydraulics, that you needed to physically turn off in order to exit the machine or enter the machine, then it wouldn’t have happened.”

The operators were asked about excavator design features that, in their experience, were more likely to cause IOOC. Opinions included:

- Confined/smaller cab spaces
- The safety lever design on some models do not isolate all of the systems e.g. the boom and slew functions are isolated but the track hydraulics are left operational, the position of the lever at the cab entrance increasing the likelihood of catching loose clothing, floppy safety levers i.e. safety levers designed with flexible ends.
- Poor visibility
- Controls positioned too close to arms and feet

Several respondents mentioned specifically that, in their opinion, the standard design/position of the safety lever compromised safety, and that it should be replaced by a switch positioned away from the cab entrance.

### 4.3.4 Control measures to mitigate the consequences of IOOC

The operators were asked to assess the effectiveness of seven control measures designed to mitigate the risks related to IOOC. The most popular options, ranked in terms of perceived effectiveness are:

- Touch sensitive joy sticks\(^5\)
- Enable switches\(^6\)
- Seat switches\(^7\)
- Control isolation levers/switches\(^8\)

The operators were also asked which their most preferred control measure was. Table 4 summarises their responses:

---

\(^5\) An isolation switch (typically linked to a time-out feature) that has to be operated to make the hydraulic systems of the machine operational.

\(^6\) An isolation switch (typically linked to a time-out feature) that has to be operated to make the hydraulic systems of the machine operational.

\(^7\) A pressure operated isolation switch located under the seat of the excavator. If the operator gets out of the seat, the seat switch opens and isolates the excavator hydraulic systems.

\(^8\) A lever positioned to the left of the operator that he/she has to raise in order to activate the excavator hydraulic systems. The safety lever is positioned so that when raised, it restricts the operator’s access and egress into the cab. The safety lever is specifically designed to mitigate the risk of IOOC during access and egress from the cab.
4.3.5 IOOC control measures usability, reliability and defeatability

Most respondents saw the control measures as easy to use. The ease of use of enable switches, control isolation levers, seat belt switches, seat switches and touch sensitive joysticks were all mentioned specifically. The majority of operators thought that the control measures addressed the realities and practicalities of operating excavators, and would not adversely impact on comfort, convenience or productivity. For example, only two respondents thought that enable switches may adversely affect productivity.

In terms of reliability of the control measures, similar response patterns emerged with the majority of operators seeing the control measures as reliable and working across most situations. Some operators reserved their opinion about reliability, taking the position that control measure reliability depends on technology on which the control measures are based, with touch sensitive joysticks a good example to illustrate.

A majority of operators took the position that control measures could be defeated or bypassed, with seat belt switches singled out as a good example of an easy to bypass measure. About half of respondents said that they could not see a reason to bypass control measures. Others were prepared to suggest reasons as to why operators and site colleagues may be motivated to bypass. Possible reasons for bypassing include:

- Convenience
- Laziness
- To save time
- If the control measure malfunctioned
- Reduced productivity

4.4 ELIMINATING IOOC ISSUES THROUGH IMPROVED DESIGN – OPERATOR IDEAS AND OPINIONS

A majority of operators agreed that IOOC issues could be eliminated through improved design of the excavator, outnumbering those that took the opposite view by approximately two to one. Their suggestions included:

- Better visibility

<table>
<thead>
<tr>
<th>Control measure</th>
<th>Number of preferences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Touch sensitive joystick</td>
<td>11</td>
</tr>
<tr>
<td>Seat switches</td>
<td>7</td>
</tr>
<tr>
<td>Enable switches</td>
<td>5</td>
</tr>
<tr>
<td>Delay timers</td>
<td>4</td>
</tr>
<tr>
<td>Control isolation levers</td>
<td>3</td>
</tr>
<tr>
<td>Seat belt switches</td>
<td>2</td>
</tr>
</tbody>
</table>
• Replacing the safety lever with a delay timer switch and
• Re-designing the safety lever.

Several suggestions related to the control measure ideas mentioned previously in the interviews, suggesting that those discussions had influenced responses to the improved design question. Some operators responded to this question by suggesting training rather than technological solutions e.g. stricter procedures for working with banksmen.

The views of operators not seeing better design as a way forward are illustrated in the following quotes:

“I don’t think there’s anything wrong with the design of the excavator I think, like I said previously, I think it’s just, the accidents that do happen is down to human error”

“Not really no, there’s not much more, there’s nothing really you can do, it’s down to driver error really a lot of it”

“I think, I think we’re barking up the wrong tree really, I think the men on the ground ought to be trained more”

“I don’t think you could really redesign the cab that much, because you’ve only got a certain size that you’ve got to work with”

“There’s nothing wrong with the design of them”

“There’s nothing you can really change on an excavator other than some way of killing that power”
5. CONCLUSIONS

5.1 SUBJECT MATTER EXPERT INTERVIEWS

5.1.1 Perceptions of the limited effectiveness of current hardware control measures to prevent IOOC

Some subject matter experts, including those working for manufacturers, are sceptical about the effectiveness of current hardware control measures such as cab entrance located safety control levers. Their views about the basic nature of existing hardware control measures, coupled with these measures “not really addressing the risks” and the potential of defeatability, cast doubt on the robustness of existing control measures.

5.1.2 From a technological perspective, possibly more could be done to better manage the risks of IOOC

Current IOOC prevention measures engineered at the system level are somewhat limited i.e. focus mainly on the risks associated with cab access and egress. Some respondents were of the opinion that much more could be done to push the “technological boundaries” and build in preventative measures as part of the design process. Crucially, however, these measures need to be highly practical, and avoid, at all costs, any impact that could slow the operator down.

5.1.3 Biased perceptions of the basis of IOOC risk

Feedback from subject matter experts suggests that excavator IOOC is a complex, multifaceted issue that presents a significant, clear and present risk. However, a logical analysis of the risks suggests that IOOC causality can be attributed to operator related or ergonomic/design reasons or both. The tendency of the manufacturer based subject matter experts to see the risk of IOCC as associated with operator error and context of use, rather than being additionally linked to control and system design, suggests that the latter is a neglected perspective for manufacturers.

5.1.4 Possible commercial barriers to changing control system design

Respondent feedback suggests that manufacturers are very sensitive to “market forces” and feedback from customers when considering major changes to product design. This observation could prove to be a significant barrier to incorporating design based changes aimed at mitigating the impact of IOOC i.e. manufacturers appear concerned about employing non-standard approaches to design and layout. Unless discussed openly with manufacturers, this situation has the potential to impede progress in control system design solutions to mitigate IOOC risk.

5.1.5 Manufacturers are possibly under-utilising the potential of technological, ergonomic and human factors expertise to address IOOC risks

Integrating these conclusions based on the subject matter expert interviews implies that manufacturers could be under utilising the potential of technological, ergonomic and human factors expertise in the design of hardware control measures designed to mitigate the risks of IOOC. Combining an ergonomic and human factors approach with innovative technology could offer a way forward for excavator manufacturers to more effectively address the risks from IOOC. Tackling the causes of IOOC from a technological/ergonomic/design perspective seems a fruitful direction to explore with excavator manufacturers. The information gathered in these interviews suggests that more could be done to design out IOOC risk at source.
5.2 OPERATOR INTERVIEWS

5.2.1 Operators perceive IOOC as a problem

The majority of operators interviewed regarded IOOC related risks in excavators as either a problem or a serious problem. Operators viewed IOOC related risks independent of excavator size and make/model, suggesting that machine related IOOC risks are not only uniform across the different use contexts, but may also be related to similarities in cab design/layout. This observation indicates that IOOC is an issue that spans all manufacturers of excavator equipment.

5.2.2 IOOC occurs reasonably frequently

The findings suggest that there are plenty of opportunities for accidents and near misses. Operator IOOC incident estimates are likely to be an underestimate given the wide variability in the data and the finding that some operators claim that IOOC incidents do not happen to them (the latter observation could be attributable to an artefact of the research design, with operators, for whatever reason, not willing to admit to committing operational errors). Although it is likely that most IOOC incidents do not result in accidents or near misses, reducing the incidence rate would result in a lessening of the IOOC accident rate.

5.2.3 Operators think IOOC risk could be reduced through improved excavator design and the introduction of new technology

A majority of the operators interviewed said that improved design could reduce the risks related to IOOC. This suggests that making technical changes to the somewhat uniform design features common to most makes/models is a potentially fruitful path to IOOC risk reduction that has not yet been addressed by manufacturers. Operators suggested manufacturers could radically re-design and/or re-think the standardised safety lever concept. There was significant support for the idea of touch sensitive control joy sticks, which operators thought would be highly preventative of IOOC situations while having minimal impact in standard operational circumstances. The views of the operators suggest that there is more that manufacturers could do to reduce IOOC risk by re-thinking design and technology.

5.2.4 Usability, productivity and reliability issues would not be a barrier to technical innovation

The vast majority of operators said that the control measure concepts described to them would not impact adversely on the usability of machines, nor adversely impact on comfort, convenience or productivity. They also thought that the control measures would prove reliable across most situations.

---

9 IOOC incidents are instances where operators report operating the controls unintentionally, with or without people in the vicinity and with or without a harm outcome.
6. GLOSSARY OF TERMS

- **Joystick control** – hand operated control lever controlling various machine functions such as rotation and the movement of the excavator boom, stick and bucket.

- **Enable switch** – an isolation switch (which can be linked to a time-out feature) that has to be operated to make the hydraulic systems of the machine operational.

- **Seat belt switch** – an isolation switch incorporated in the seat belt system that detects whether the seat belt is in use. The excavator hydraulic systems are actuated only when the operator links together the two halves of the seat belt.

- **Seat switch** – a pressure operated isolation switch located under the operators seat of the excavator. If the operator gets out of the seat, the seat switch opens and isolates the excavator hydraulic systems.

- **Touch sensitive joystick controls** – a joystick control engineered using technology that senses the presence of a human hand. A touch sensitive joystick control will only interface with the excavator hydraulic systems when the operator’s hand is physically on the control lever.

- **Safety lever** – a lever positioned to the left of the operator that he/she has to raise in order to activate the excavator hydraulic systems. The safety lever is positioned so that when raised, it restricts the operator’s access and egress into the cab. The safety lever is specifically designed to reduce the risk of IOOC during access and egress from the cab.

- **Dead man's controls** – a failsafe device which stops movement in the event that pressure is released from the control (typically lever or trigger) by the operator.

- **Radar proximity detection systems** – a radar device use detect the presence of objects/persons in the immediate vicinity of the machine.
7. APPENDIX 1: SCHEMATIC CAB DIAGRAM
8. APPENDIX 2: SUBJECT MATTER EXPERT INTERVIEWS

QUESTION SET

Identification and critical evaluation of measures to prevent the inadvertent operation of controls (IOOC) on excavators - experts interview questions

We (the Health and Safety Laboratory) have been commissioned by the HSE to conduct research into the causes of, and possible solutions to, accidents caused by the inadvertent operation of excavator controls. The research aims to:

- Identify the different ways in which IOOC might occur;
- Identify the various design control measures that prevent or mitigate the consequences of IOOC and
- Seek views regarding usability, reliability, defeatability and anthropometrics; and identify the best design control measures

The information you provide to us will be confidential and non-attributable. To ensure we accurately capture your comments, we would like to record and transcribe your comments. Do you agree to this? The interview will last between one and one and a half hours.

1. Background information
Aim: To establish experience, training, current role and role history:

- What does your job role consist of?
- What experience do you have in relation to excavators?

Probe: have you had any excavator related training?

- What experience and/or training do you have in relation to excavator control design and/or control design for other equipment?

- To what extent have you been involved in equipment trials and the design of operator controls/layout?

- What are the main factors that influence the adoption of excavator control design and layout?

- As part of your role, do you establish if there are deficiencies in current safeguarding measures?

Probe: e.g. press reports, feedback from supply chain, end-users etc

2. Perception of risks
Aim: To identify experts' perceptions of the major risks working with excavators and to gain insights into where IOOC fits within the overall risk profile when working with excavators.

- What do you think are the main risk and/or hazard when working with excavators?
• What other risks and/or hazards do you think there are?
  Probes:
  • What do you understand by the term "inadvertent operation of controls"?
  • What is the relative likelihood of "inadvertent operation of controls" compared to the other example?
  • Who is at most risk from "inadvertent operation of controls" and what harm outcomes/ injuries can occur?

• Have you had experience of operating excavators?
  If yes:
  • Have you had any personal experience of "inadvertent operation of controls" (i.e. a near miss) when operating excavators?
  • If so, how has this affected the way you perceive the risk?
  • Has this experience influenced design decisions in any way?

3. Inadvertent operation of controls
Aim: To identify the different ways in which IOOC might occur.

• What are all the different ways you think "inadvertent operation of controls" can occur (try and elicit exhaustive list)

• What do you think are the main factors that contribute to "inadvertent operation of controls"?
  Probes:
  • Person factors (competence/ risk perception/ hazard awareness)
  • Site factors?
  • Design of controls and cab environment?

• How much of a risk is "inadvertent operation of controls"?

• How often does "inadvertent operation of controls" occur?

• Are there any particular situations in which people are more likely to inadvertently operate the controls?

• What are the most common "inadvertent operation of controls" near misses in excavator work?

• Is there anything that makes it difficult to avoid "inadvertent operation of controls"?
  Probe: type of clothing worn

4. The standardisation of excavator controls (for trainers and end users)

• Are there any new makes and models of excavators where the main control functions differ from the current "standard" configuration?
  Probe: If so, which ones and how do they differ?

• Are there legacy makes and models where the main control functions differ from the current "standard" configuration?
  Probe: If so which ones and how do they differ
• Do you think non-standard controls could be a significant contributory factor in IOOC incidents and near misses (e.g. transfer of learning effects when operators switch between machines etc.)

5. Control measures that prevent or mitigate the consequences of IOOC

Aim: To identify the control measures to prevent or reduce the risks associated with "inadvertent operation of controls".

• (For manufacturers only) – has your organisation carried out a formal machinery risk assessment that has identified the risk of "inadvertent operation of controls"?
  Probe: If so what control measures were deemed sufficient?
  What control measures do you have in place to prevent or reduce the risks associated with "inadvertent operation of controls"?

• As you familiar with the requirements in EN 474 – 1 to prevent the inadvertent operation of controls in the cabs of excavators?
  If yes, what do you think of the adequacy of the standard to control "inadvertent operation of controls" (i.e. only applies to access/egress, not to "inadvertent operation of controls" when sealed at the controls)

• Are control measures adopted different for different sizes of excavator? (e.g. are the same provisions provided for mini excavators where controls could be activated from a standing position on the ground compared with larger machines where the controls can only be accessed from within the cab)

• (For manufacturers only) What control measures are you aware of on other makes and models of excavators to prevent or reduce the risks associated with "inadvertent operation of controls"?

• What other control measures are you aware of which are used on other mobile plant (i.e. excluding excavators) to prevent "inadvertent operation of controls"?

• In your opinion, what other control measures/ technology could potentially be used to prevent "inadvertent operation of controls"?

• How practical are the control measures in current use either on excavators or other mobile plant?
  Probe: Are they easy to use?
  What feedback have you received from users?
  Can they be defeated?

• (For manufacturers only) Were you or your colleagues involved in developing the control measures?

• What could make it easier to avoid "inadvertent operation of controls"?

• Are you aware of any limitations regarding the implementation of other methods to prevent "inadvertent operation of controls"?
6. Controls measures: usability, reliability, defeatability, and anthropometrics

Aim: To establish perceptions on the usability, reliability, defeatability and anthropometrics in relation to IOOC control measures.

- How effective are the hardware control measures in place to avoid IOOC?
  
  Probes:
  - Do they work?
  - Are they reliable?
  - Do they address the realities and practicalities of operating excavators?
  - Do they address the risks associated with IOOC?
  - What is the basis for your opinion? e.g. results from formal trials or anecdotal feedback from the field.

- Are there any ways that the control measures can be bypassed?

- Are you aware of reasons why operatives might be motivated to bypass them?
  
  Probes:
  - To save time?
  - To make operations easier?

- To what extent have ergonomics/human factors approaches been employed to make the control measures more usable?

- (For manufacturers only) Has the company employed external human factors/ergonomics consultants to advise on design matters relevant to “inadvertent operation of controls”?

- (For manufacturers only) Has the company looked at, or considered, any of the following safety devices to prevent “inadvertent operation of controls”?
  - enable switches (in addition to the safety lever)
  - seat switches
  - delay timers synchronised with the safety lever
  - dead man’s controls
9. APPENDIX 3: OPERATOR INTERVIEWS QUESTION SET

Project title: Identification and critical evaluation of measures
to prevent the inadvertent operation of controls (IOOC) on
excavators

End-user interview questions

Aims of the research
• To gain detailed insight into the differing ways IOOC might occur.
• To identify the full range of control measures, as supplied or retro fitted that are being
  used, or could be used to either prevent the IOOC or which reduce the risks
  associated with the IOOC.
• To seek expert and end-user views on the likely efficacy of the different design
  control measures taking into account considerations such as usability, reliability,
  defeasibility and anthropometrics.

Objectives
• Identify the different ways in which IOOC might occur.
• Identify any near misses operators may have experienced.
• Identify operator behaviours, motivations and attitudes relevant to IOOC.
• Seek views regarding usability, reliability and defeasibility of the various design
  control measures identified in the SME interviews, and identify those that the
  operators judge to be the best and which merit being carried forward to field trials.

Background information (Aim: To establish experience, training, & current role)

1. What does your job consist of?

2. How long have you operated:
   • excavators?
   • mini excavators?

3. When did you attend your last training course for operating
   excavators?

4. Who awarded your licence and what class of excavators can you
   operate? What are the excavators you cannot operate because you do
   not have the qualifications for?

5. Do you own your own excavator or is it a hire or lease machine?

Perception of risks (Aim: To identify perceptions of the major risks working with
excavators and where IOOC fits within the overall risk profile)

We are looking at what we call “Inadvertent operation of controls”
(IOCC) of excavators. This simply means a situation that is the
accidental movement and operation of switches/levers that cause the
excavator to move in a way that you didn’t intend.
6. How significant a problem do you think accidental operation of controls is relative to other risks of operating excavators?

7. What kind of accidental actions can happen when you operate the excavator? e.g. when getting into and out of the cab/ when sitting in the seat/ when ‘standing in the cab’/ effect of clothing/ distraction in the cab/ sneezing etc.?)

8. Does the size of an excavator matter in relation to the risks of incidents happening?

9. What situations are likely to result in near misses resulting from accidental actions?

10. In your experience - are some makes/models of excavators less likely to prevent accidental actions/incidents than others - if so why?

11. What could make it easier to avoid accidental actions? (Probe: e.g. contact with placed or dropped objects, clothing and parts of the body)

**Personal experience of involuntary actions** *(Aim: Circumstances in which a personal IOOC experience occurs and if risk perception has changed)*

12. How many times, on average, do you think you accidentally operate the controls in a year?

13. Please tell us about any personal experiences of accidentally operating the controls causing a dangerous movement of the excavator or its boom?

14. Has this changed how you operate the excavator now? E.g. how you work with others (e.g. ground workers) in the vicinity of the machine?

15. What were the particular circumstances in which the accidental actions occurred?

16. From your own perspective could this have been prevented by a change in the design of the excavator?

17. From your own experience are there any particular design features on excavators which are more likely to cause involuntary actions (prompts: the cab layout whether the safety lever is an integral part of the armrest or it is separate how easy it is to step over the safety lever are there any circumstances where you may now want to use a safety lever in an excavator.

18. Were you aware of the risk of accidental actions previously?
Control measures that prevent or mitigate the consequences of AOOC
(Aim: Respondent's opinions about the effectiveness of specific types of control measure)

19. In your opinion, how effective could the following control measures/devices be applied to excavators?
   - Seatbelt switches
   - Seat switches
   - Control isolation levers
   - Enable switches (this is a switch that has to be pressed to activate the controls)
   - Delay timers – (this is a delay in the time the controls become active from when the safety lever is lowered or activated)
   - Dead man's controls – (different types that could be available)
   - Joysticks which sense contact with operators hands

Controls measures: usability, reliability, defeatability, and anthropometrics (Aim: Perceptions on the usability, reliability and defeatability in relation to IOOC control measures).

20. How easy to use are the control measures designed to avoid accidental actions?

21. Do they address the realities and practicalities of operating excavators?

22. Do they have an effect on comfort, convenience, productivity?

23. How reliable are these control measures? (I.e. Do they work in all situations?)

24. How easy is it to defeat/bypass the safeguards?

25. Why would someone want to do this?

Suggestions

26. Do you think it would be possible to eliminate the problems we just talked about through improved design of the excavator?

27. What would be your preferred solution(s) and why?

Thank you for your time

3
Inadvertent operation of controls in excavator plant - insight, analysis and recommendations for prevention by design

There is extensive anecdotal information available, particularly from large construction contractors, which suggests that inadvertent operation of controls (IOOC) on excavators is a significant issue. Any inadvertent operation of excavator controls has the potential to cause serious injury or death; whether or not injury occurs is only a matter of chance.

This study was commissioned by HSE to gather evidence in the form of views, experiences and perceptions of both excavator operators, and subject matter experts working for both excavator manufacturers and for a major training provider. The aims of the research were to:

- Gain insight into the differing ways IOOC might occur;
- Identify the full range of control measures to prevent or mitigate the impact of IOOC; and
- Seek expert and end-user views on the likely efficacy of different design control measures.

The research identified that operators perceived IOOC as a problem and it was their view that IOOC risks could be reduced through improved excavator design and the introduction of new technology. They did not see usability, productivity and reliability issues as being barriers to introducing design and technical changes aimed at reducing IOOC risks.

Subject matter experts considered that more could be done to better manage the risks of IOOC using new technical solutions. Some manufacturer based subject matter experts associated the risk of IOOC with operator error and context of use, rather than being additionally linked to control and system design.

Manufacturers are possibly under-utilising the potential of technological, ergonomic and human factors expertise to address IOOC risks.

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.