ERROR REDUCTION IN MEDICINE

FINAL REPORT TO THE NUFFIELD TRUST

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Executive Summary

The Department of Health report ‘An Organisation with a Memory’ issued in 2000, along with other publications, highlights major patient safety problems of the NHS in the UK. Various tools and methods for the investigation and analysis of adverse events and critical incidents already exist. However, it is not clear to what extent solutions to such problems are addressed or what tools are used to elicit effective measures to resolve or rectify the causes. The identification of such solutions in industries such as aviation and nuclear power are known as error reduction strategies and various error reduction techniques have been established to help with this process.

We reviewed the range of error reduction methods available in high-risk industries to determine their core characteristics and potential applicability within healthcare. In high risk industries error reduction methods are included in the field of Human Reliability Analysis (HRA). The application of such error analysis techniques to the problem risk in healthcare is rare. Though the scarcity of HRA techniques in healthcare is likely to be due in some part to the safety culture, much is likely to be due to a lack of awareness of the usefulness of the techniques and their applicability to the problem of human error in the clinical context. Techniques vary in their scope and have been grouped into those that focus on: data collection, task description, task simulation, human error identification and analysis, and human error quantification. Techniques may cover one or more of these aspects, for example, THERP, HEART and SHERPA include both human error identification and analysis, and human error quantification tools.

In the second phase of this project we adapted a risk assessment technique called ‘Barrier Analysis’ and used it to look at the barriers or safeguards in the medication process to prevent harm to the patient in. Eight senior staff were interviewed to identify the barriers or safeguards currently in place. This technique was expanded to look at circumstances that break down these safeguards. Recommendations were elicited from the respondents on how to improve current safeguards or to reduce unwanted circumstances that hinder the safe-running of the medication process. This study shows that barrier analysis is a feasible method that can be easily adapted to produce useful insights in error reduction in healthcare.

Our review identified 35 HRA techniques that have the potential for identifying error reduction strategies in healthcare. However, though HRA is designed for ‘error reduction’ and while many of the techniques listed address error identification, classification and quantification, they do not necessarily provide the next step of helping users develop error reduction strategies. It is assumed that those with local and domain-specific knowledge will be able to solve error related problems identified with the specific techniques. While some areas of healthcare have used certain HRA techniques, there is considerable scope to use others and to apply techniques to other aspects of healthcare not yet explored. There is a lot of potential for further research and this review is an initial step in helping those interested to choose a suitable technique or tool to their field.

Contents

Principal Abbreviations and Acronyms

A&E	Accident and Emergency Department
CREAM	Cognitive Reliability and Error Analysis Method
HEA	Human Error Analysis/Assessment
HEART	Human Error Assessment and Reduction Technique
HERA	Human Error in Air Traffic Control project
HRA	Human Reliability Assessment / Analysis
JHEDI	Justification of Human Error Data Information
HTA	Hierarchical Task Analysis
NATS	National Air Traffic Services
NPSA	National Patient Safety Agency
PHEA	Predictive Human Error Analysis technique
SCHEMA	Systematic Critical Human Error Management Approach
SHERPA	Systematic Human Error Reduction and Prediction Approach
TAFEI	Task Analysis for Error Identification
TALENT	Task Analysis-Linked Evaluation Technique
THERP	Technique for Human Error Rate Prediction
TRACEr	Technique for the Retrospective and predictive Analysis of Cognitive Errors

Other techniques are listed in Appendix 1

1. Introduction

Several important new initiatives in the last five years underline the increasing attention paid to patient safety. In the United States organisations such as the National Patient Safety Foundation are pioneering a much more sophisticated approach to patient safety, drawing on research and practice from a number of different industries. The recent report of the Institute of Medicine on ‘Building a Safer Healthcare System’ (Corrigan et al., 1999) starkly sets out the scale of harm to patients, and an ambitious and radical agenda for change, which attracted Presidential backing in the United States. In Australia the results of the Australian Quality in Healthcare Study (Wilson et al, 1995) were initially marred by political interference, setting back the implementation programme that was to follow. High profile cases in several countries, such as, the Bristol Inquiry into paediatric cardiac surgery in the UK, and the Winnipeg inquiry in Canada also played a part in raising public awareness and driving policy change (Smith, 1998). However major initiatives are now underway at both a federal and national level. The British Medical Journal devoted an entire issue to the subject of medical error (Leape and Berwick, 2000) in a determined effort to move the subject to the mainstream of academic and clinical enquiry, and other leading journals are now running series on patient safety. There are also initiatives in Canada, several countries in Europe and Asia with an increasing interest in research on patient safety and practical approaches to the management of risk.

In the United Kingdom a study from our research group, funded by the Nuffield Trust, has suggested that over 10% of patients admitted to UK hospitals are harmed as a result of the treatment they receive, and that half of these ‘adverse events’ are preventable (Vincent et al., 2001). The direct cost of these preventable events to the NHS, in terms of extra days in hospital, is estimated to be in the region of £1 billion per annum. The Chief Medical Officer’s report ‘An Organisation with a Memory’ (Department of Health, 2000) quoted these and other figures, such as the high rate of in-patient suicides, to underline the major patient safety problems of the NHS and other advanced healthcare systems. The new National Patient Safety Agency (NPSA) represents an initial response to these problems with its remit to develop a national incident reporting system and to promote learning from adverse incidents throughout the NHS. The NPSA is currently developing training to healthcare organisations on human factors incident investigation and analysis methodologies using a root cause analysis approach.

As yet however none of the various incident investigation and analysis methods have been developed to the point where they could provide clear indications of solutions to the problems uncovered. The identification of such solutions in industries such as aviation and nuclear power are known as error reduction strategies and various error reduction techniques have been established to help with this process. Therefore the next step for healthcare, addressed in the present proposal, is to specify error reduction methods at the conclusion of incident investigations and to explore error reduction strategies for more general application.

Models of accident investigation and analysis developed in other industries seem to have transferred reasonably well to healthcare, but we do not yet know whether error reduction methods developed in highly proceduralised industries will transfer to healthcare equally effectively. Industrial methods, unlike health service models, often contain a module on error reduction to facilitate organisational learning. If we could link specific error reduction techniques to the findings of investigations, rather than just making broad recommendations, the impact and value of such investigations would be greatly increased. There are of course a number of models and techniques of quality improvement available in healthcare, but they tend to be broad-brush interventions, which do not address the specific precursors of errors or the contributory organisational factors (Vincent, et al, 1998).

The project reviewed the range of error reduction methods available in high-risk industries to determine their core characteristics and potential applicability within healthcare. We have identified the principal techniques available, describe the nature and purpose of the main approaches and consider how such techniques might be applied in healthcare. The review is necessarily selective and we do not claim that the techniques we list are the only candidates for use in healthcare. Rather we have attempted to provide an introduction and overview of the area so that those seeking to use these approaches can orient themselves in the field and, hopefully, save a great deal of time. Some might consider retrospective incident analysis techniques (e.g. RCA) as belonging to this field of human reliability but these are not included here as such techniques are already widely applied in healthcare and have been extensively discussed elsewhere (Vincent 2003, JCAHO 2000, Busse & Johnson 1999). Here we focus on techniques that examine the processes or systems of work.

Following the review, we have attempted to show how a specific technique, ‘Barrier Analysis’, could be applied in a healthcare environment, specifically to the issue of medication practice in the Accident and Emergency (A&E) environment. Barrier Analysis has been used in industry to look at the barriers or safeguards that protect vulnerable objects from harmful ‘energy’ and it was considered feasible to apply this to healthcare. We also adapted the technique to look at the factors that could make the safeguards fail – in the shape of a concept called ‘barrier-breakers’ – these are comparable to the contributory factors used in the London Protocol (Vincent et al 1998; Taylor-Adams and Vincent, 2004).

2. Principal Aims of the Research

The principal aims of the research are as follows:

- To review error reduction methods used in high-risk industries and assess their potential utility in healthcare.

- To review methods of error reduction in healthcare to determine the range and nature of available methods.

- To pilot an error reduction technique in a clinical setting.

3. Research methodology

To meet the aims listed above, the research methodology was defined as follows:

- Perform literature search for techniques in error reduction both in the field of health care as well as from other high-risk industries
- Identify criteria for selecting a short-list of error reduction techniques for experimental application in the health-care environment

- Identify the short-list and a first method for piloting
- Identify relevant health-care systems for application of the chosen methodologies
- Justify the choice of particular health-care systems as examples for application of the method – using feedback from personnel as well as incident reports
- Implement the method
- Implement any error reduction solutions identified
- Obtain feedback on the error reduction solutions

4: Literature Review

4.1: Literature Search

The objective of this literature search was two-fold; to identify techniques that would elicit error reduction strategies as used in other high-risk industries; and to identify publications that described specific error reduction solutions that had been implemented in medicine.

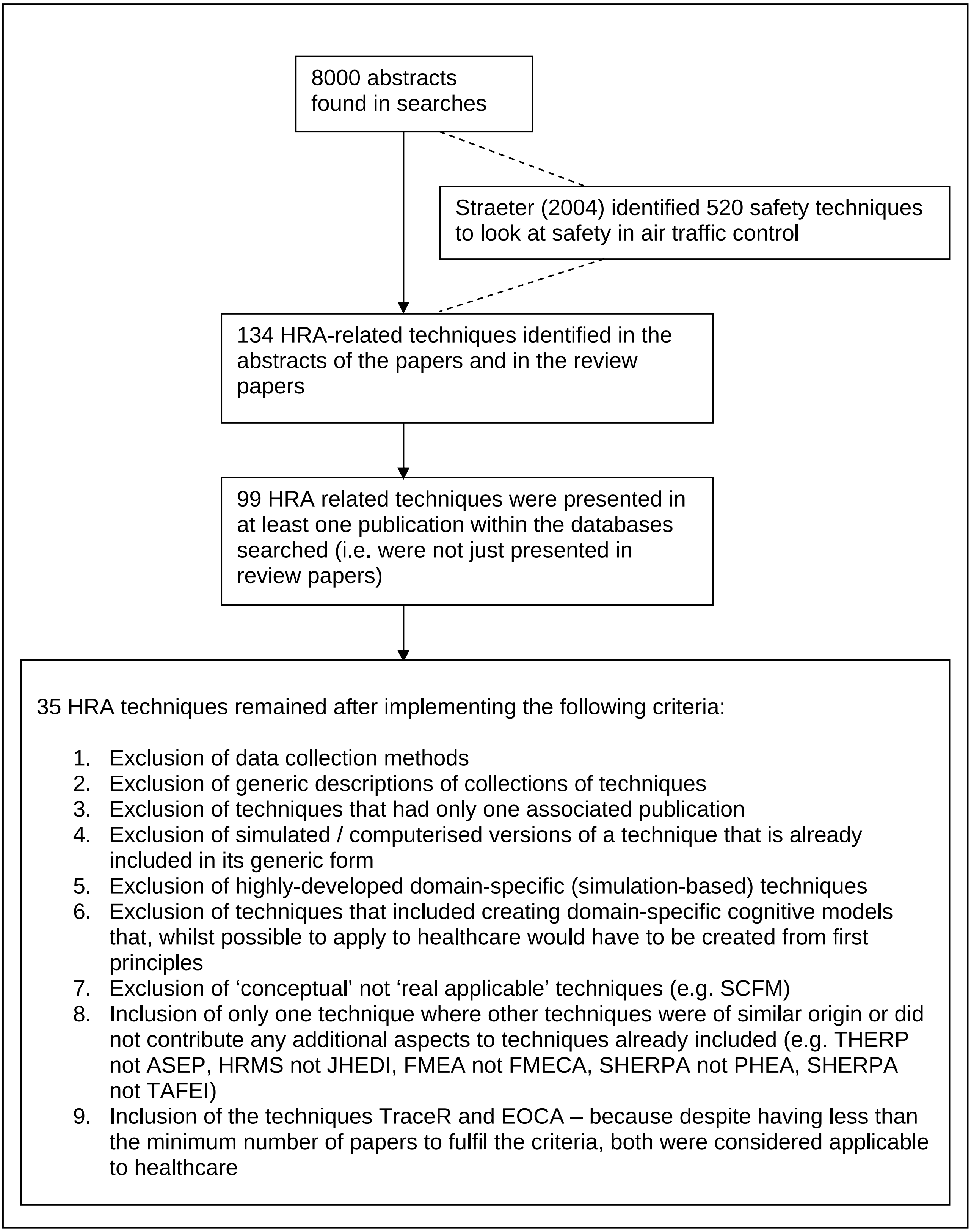
The search was carried out using three relevant databases – namely PSYCHLIT, Ergonomics Abstracts and MEDLINE.

These were deemed to be sufficient to cover all relevant and general error reduction research in the field Human Factors (through PSYCHLIT & Ergonomics Abstracts) as well as any error reduction techniques or solutions that were presented specifically in the medical sector (using MEDLINE).

The results of the search are presented in Appendix 2 and include the name and date on which the database was first searched (with the author occasionally returning to recollect information as the project continued), the search term and the number of hits obtained. As can be seen from the table, search terms covered both generic HRA terms such as ‘human reliability’ and ‘human error analysis’ (as shown in the top of the table) and specific terms such as ‘Failure Modes Effects Analysis’ and ‘Fault Tree Analysis’ (as shown in alphabetical order in the bottom of the table). A small number of techniques not identified in the main search, but known to the first author (ML) were also included.

8000 abstracts were reviewed in total, revealing 134 techniques including data collection and task description techniques, through the human error identification phase through to the elicitation of performance shaping factors and human error probabilities. A full list of these 134 techniques is shown in Appendix 3 including references where these techniques have been cited, described or have been applied in practice as appropriate. It should be noted that a review by Straeter (2004) identified 520 techniques to look at safety in air traffic control so these 134 should not be considered an exclusive list – but perhaps more a reflection of the relationship between safety practitioners and research publications as well as the nature of safety techniques to be given a number of different names depending on the current trend and the industry in which they are applied. Of the 134 techniques identified, 99 had papers published upon them directly within the databases searched. This process of selection of techniques in illustrated in Box 1.

Box 1: Flowchart for selection of techniques



8000 abstracts found in searches

Straeter (2004) identified 520 safety techniques to look at safety in air traffic control

134 HRA-related techniques identified in the abstracts of the papers and in the review papers

99 HRA related techniques were presented in at least one publication within the databases searched (i.e. were not just presented in review papers)

35 HRA techniques remained after implementing the following criteria:

1. Exclusion of data collection methods
2. Exclusion of generic descriptions of collections of techniques
3. Exclusion of techniques that had only one associated publication
4. Exclusion of simulated / computerised versions of a technique that is already included in its generic form
5. Exclusion of highly-developed domain-specific (simulation-based) techniques
6. Exclusion of techniques that included creating domain-specific cognitive models that, whilst possible to apply to healthcare would have to be created from first principles
7. Exclusion of ‘conceptual’ not ‘real applicable’ techniques (e.g. SCFM)
8. Inclusion of only one technique where other techniques were of similar origin or did not contribute any additional aspects to techniques already included (e.g. THERP not ASEP, HRMS not JHEDI, FMEA not FMECA, SHERPA not PHEA, SHERPA not TAFEI)
9. Inclusion of the techniques TraceR and EOCA – because despite having less than the minimum number of papers to fulfil the criteria, both were considered applicable to healthcare

Of these 99, many of the techniques were conceptually similar to other techniques. For example, some bore a strong resemblance to the SHERPA concept of using a task analysis, applying a set of ‘error mode’ guide words to identify errors, then either use descriptions to quantify the error probability and/or identify the ‘performance shaping’ or contributory factors likely to influence the probability of this occurrence. Whilst the newer generations of SHERPA used slightly different error modes or slightly different descriptions of performance shaping factors, this did not warrant their inclusion in the final list. Thus those interested in evaluating the following techniques TEACHER, SIERRA, SCHEMA and PHEA in comparison to SHERPA are urged to do so. Similarly DARE, PROFAT and Safecon are all based on a fault tree concept, HERMES is included due to being part of DYLAM and these have also been excluded at this stage.

Other techniques provide additional contributory aspects to more established techniques. For example, HAZAN is known as the quantitative addition to HAZOP and therefore was excluded; and FMECA adds the element of ‘criticality’ to FMEA and HEMECA adds the human element.

Furthermore, many researchers have generated similar versions of the same technique – one detailed and rigorous, the other simpler and quicker to use. To further reduce the number of techniques for consideration, the following criteria were applied:

1. Techniques that had ONLY one publication were excluded
2. Techniques that were simply data collection methods were excluded (for example, the critical incident technique, observation, structured interviews, etc.)
3. Generic descriptions of collections of techniques were excluded, for example, PRA (probabilistic risk analysis/assessment), simulations and RCA (root cause analysis) which could involve a toolbox of any number of techniques.
4. Simulated / computerised versions of a technique that is already included in its generic form were excluded, For example, GAMEES was rejected because it is based on Influence Diagrams which have been included and SEAMAID because it is based on Petri-nets. Likewise TALENT is based on HTA and timeline analysis, TAFEI is based on task analysis and State Space Diagrams HEDOMS relies on GEMS and FMEA and STARS is a toolkit to perform FMEA, FTA, IRRAS is based on FTA.
5. Highly-developed domain-specific (simulation-based) techniques were excluded, for example INTEROPS, DYLAM due to their high nuclear domain-specificity.
6. Techniques that included creating domain-specific cognitive models were excluded because, whilst viable in healthcare, if applied, would have to be created from first principles anyway – these include SYBORG, COSIMO, RPDM and CES.
7. Conceptual not real applicable techniques were rejected – SCFM
8. Where the techniques were of similar origin or did not contribute anything additional to techniques already included, only one of the category of techniques was used – this would occur when technique developers would invent a simpler and easier to use version of the detailed method they had developed. Therefore THERP was included and not ASEP, HRMS was included and not JHEDI, FMEA not FMECA, SHERPA not PHEA and SHERPA not TAFEI.

9. However, despite fitting the exclusion criteria, the techniques TraceR and EOCA were included – because despite having less than the minimum number of papers to fulfil the criteria, both were considered potentially applicable to healthcare.

Thus this list of techniques provided us with a solid overview of all the HRA techniques available as well as a realistic perspective on which techniques should be applied initially to healthcare problems.

4.2: Findings from the literature review

4.2.1: What is Human Reliability Analysis?

Human reliability analysis (HRA) identifies the errors and weaknesses in the system by examining the systems of work including those who work in the system. The ultimate goal of HRA is to improve reliability and safety. Healthcare professionals, whether clinicians, managers or researchers, who wish to use human reliability techniques face a daunting task. There is a vast number of these analytic techniques, derived by different people in different industries for different purposes. Most are commercial in origin, often not published in the academic literature and not subject to formal evaluation or validation and a large number of opaque acronyms (Appendix 1). The strongest influence of human reliability approaches has been on the analysis of serious clinical incidents in healthcare, which have drawn on the critical incident technique (Flanagan 1984, Kirwan & Ainsworth 1992), root cause analysis (JCAHO, 2000) and other methods. The organisational accident model of James Reason has been particularly influential (Reason, 1997; Vincent, 2000, 2003) in providing the foundations for a broader, systems view of error and safety. In the last few years however there has been growing interest in a wider range of safety and reliability techniques used in other industries. For instance the Veterans Affairs Patient Safety Programme has developed a healthcare 'failure modes and effects analysis' (FMEA), using elements of classical FMEA, their own root cause analysis framework and the other approaches (DeRosier et al, 2002).

Human Reliability Analysis or Assessment (HRA) falls within the field of human factors and has been defined as the application of relevant information about human characteristics and behaviour to the design of objects, facilities, and environments that people use (Grandjean, 1980). HRA techniques may be used retrospectively, in the analysis of incidents (though this occurs infrequently), or more likely prospectively to examine a system. Most approaches are firmly grounded in a systemic approach which sees the human contribution in the context of the wider technical and organisational context (Embrey, 2000). The purpose of HRA is to examine the task, process, system or organisational structure for where weakness may lie or create a vulnerability to errors, not to find fault or apportion blame. Any system in which human error can arise can be analysed with HRA, which in practice, means almost any process in which humans are involved!

4.2.2: Applications of HRA outside healthcare

Over the past 40 years, a number of industries have embraced HRA as a solution to their human factors and safety problems or have been required to apply them due to public or governmental pressure. The nuclear industry was the first to develop and apply human reliability assessment as a field in its own right (Kirwan 1994). The public fear of the risk of a nuclear reaction and the responsibility placed in the hands of a single control room operator were ensured that both the human and technological possibilities of error and breakdown were subjected to intense scrutiny. Other industries have also adopted HRA as a risk assessment strategy as the reliance on retrospective accident analysis would not preclude an incident occurring, just the opportunity to prevent a similar event from re-occurring in the future.

Since then, HRA has been applied in many 'high-risk' industries including aviation and aerospace, rail, shipping, air traffic control, automobile, offshore oil and gas, chemical, and all parts of the military (Humphreys 1988). In more mundane settings HRA has been applied to the installation of telecommunications equipment, design of computer software and hardware and to manual tasks such as lathe operation. For example, HAZOP has been applied to predict errors in response to a change in delegation of separation assurance tasks from the air traffic controller to the pilot (Shorrock et al 2003), THERP has been applied to quantify error probability and possible error reduction mechanisms concerning the distributed response to a emergency scenario in a nuclear power plant (Kirwan 1994) and SHERPA has been used to identify and predict errors in using a vending machine (Stanton & Baber 2002). Within these domains, HRA has been applied at all stages of the 'life-cycle' of a process from design of a system, normal functioning of the process, maintenance and decommissioning (Baranzini et al 2001; Nourai et al 2002).

4.2.3: Comparing healthcare and other industries

Healthcare staff may resist the application of techniques from industry on the grounds that healthcare is 'different' in some respect and cannot be treated in the same way as a production line. How far one can draw parallels between healthcare and other industries is a difficult and complex issue, in that there are undoubtedly both similarities and important differences. Aviation, nuclear power, chemical and petroleum industries and healthcare are complex, hazardous activities carried out in large, complex organisations by, for the most part, dedicated and highly trained people. The closeness of the comparison also depends very much on which aspect of healthcare one is considering and which industry. The high technology monitoring and vigilance of anaesthetists and the work of pilots in commercial aviation are similar in some respects, but the work of surgeons and pilots is very different. Emergency medicine may find better models and parallels in military or fire-fighting rapid response teams than in aviation.

There are also important differences between healthcare and other industries. Firstly, healthcare consists of an extraordinarily diverse set of activities. Healthcare encompasses the mostly routine, but sometimes highly unpredictable and potentially harmful world of surgery; primary care, where patients may have relationships with their doctors over many years; the treatment of acute psychosis, requiring rapid response and considerable tolerance of bizarre behaviour and numerous other specialties, some highly organized and routine, such as blood products; others are necessarily unpredictable, such as the rapid, constantly changing environment of Emergency medicine. Even the most cursory glance at the diversity of healthcare, the easy parallels with the comparatively predictable high-hazard industries, with usually a limited set of activities, begins to break down.

Healthcare is also much less predictable than many other kinds of work. Work in many hazardous industries, such as nuclear power is, ideally, routine. Emergencies and departures from usual practice are unusual and to be avoided. Many aspects of healthcare are also largely routine and might, in many cases, be much better organised on a production line basis. However, in certain areas, healthcare staff face very high levels of uncertainty. In hospital medicine, for example, the patient's disease may be masked, difficult to diagnose, the results of investigations may not be clear cut or the treatment might be complicated by multiple co-morbidities. Here, a tolerance for uncertainty on the part of the staff, and indeed the patient, is vital. More than other industries, the healthcare system relies on human-human interaction as opposed to human-machine interaction. There is no central focus of the healthcare staff's work such as in an aircraft or on an oil platform. In contrast, the work is focussed on a single patient as part of a flow of large numbers of patients. None of this is to say that HRA techniques should not be applied and utilised in healthcare. However, we cannot assume an easy and straightforward transition.

4.3: Screening of Techniques

As shown in the previous section and in Box 1, the literature was screened to identify a shortlist of techniques for application and experimentation. This produced a short list of 35 primary HRA techniques (the list in Appendix 1), which had either had practical application in healthcare or which were well established elsewhere and had potential application. Some techniques that appeared to be highly domain-specific have been left in this short-list; for example, ATHEANA (Dougherty, 1997) and TESEO (Bello & Colombari, 1980), used in the nuclear sector and TraceR (Shorrock & Kirwan, 2002) used in Air Traffic Management, because whilst in their current form, they cannot be used to evaluate problems in health care, conceptually an adapted version could be produced.

Following Kirwan and Ainsworth (1992) the techniques were then grouped into five categories spanning the principal types and purpose of HRA analysis. Some techniques are primarily descriptive or concern basic data gathering (Table 1). These are often used as a prelude to more sophisticated approaches involving simulation, human error analysis and human error quantification. Techniques may be used separately, but more often in combination. In the following sections we examine each of these groups in turn and, in the case of the more important groups, giving examples of their use both within and outside healthcare.

Table 1: The range and scope of HRA techniques

Type of technique	Description
Data Collection	Collection of information on incidents, goals, tasks, etc.
Task Description	Taking the data collected and portraying this in a useful form
Task Simulation	Simulating the task as described and changing aspects of it to identify problems
Human Error Identification and Analysis	Uses task description, simulation and/or contextual factors to identify the potential errors
Human Error Quantification	Estimated the probability of the errors identified

4.3.1: Data Collection

Many techniques of data collection used in HRA will be familiar to those working in healthcare. They include ethnographic observation (Chisholm et al 2001; Lally, 1999), questionnaires (Reeder et al 1997) and structured interviews (Harries et al 1996). Other techniques less common in healthcare include work sampling which examines time spent on specified activities and has been used to look at the activities in primary care (Bryant & Essomba 2004, Woelk et al 1986, Ryan & Osborne 1976) and nursing activities (Pelletier & Duffield 2003, Bobdey et al 1992). Verbal protocol analysis involves the analysis of 'think aloud' reports given while carrying out a complex task. This has been applied, for instance to heart and lung bypass surgery in simulation (Lindsay & Baber 1998) and diagnosis and decision making by physicians (Hashem et al 2003). The critical incident technique has been described elsewhere and there are often misconceptions held about the technique, for example, that it focuses only on negative, memorable incidents. For the most part, in this context, it is best seen as a forerunner of the root cause and systems approaches to case analysis that have been used in considerable number of specialities, notably anaesthetics (Thomas 2001; Galletly & Mushet 1991; DeAnda & Gaba 1990).

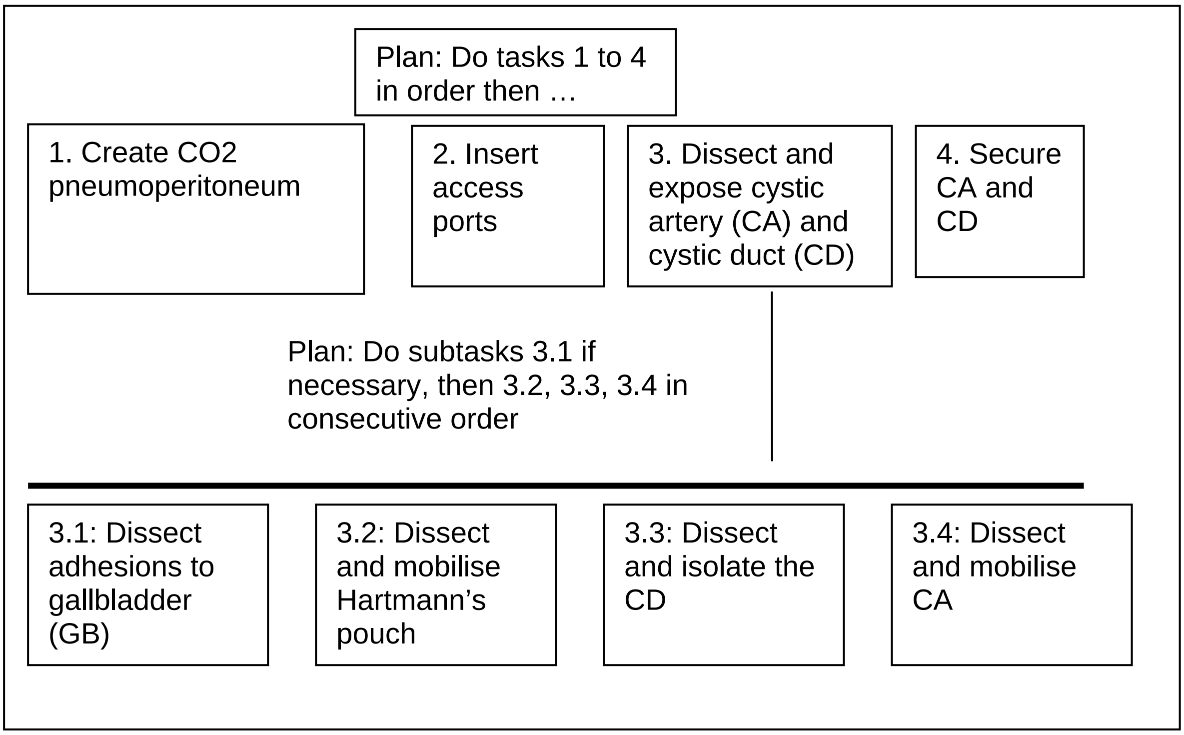
4.3.2: Task Description

Task description techniques allow the data collected to be presented in a form that is useful for error analysis and quantification. A combination of observation, structured interviews and review of available technical manuals is used to form a structured account of the exact sequence of actions needed to complete a task. Tasks may be primarily physical in nature, such as anaesthetic intubation, or cognitive such as the decision making process in Accident and Emergency triage. The way task description or task analysis is approached depends on whether the task is primarily manual or cognitive, whether it is time dependent, the complexity of the task, the number of decision points and its place in the overall work process. It is best carried out by someone who is familiar with human reliability assessment techniques but who is not familiar with the task and therefore can also explore implicit assumptions that would be made by someone who is expert at the task or the work area. Task description is a necessary foundation for error analysis, but may also be used in isolation for developing training requirements, defining job descriptions as well as for writing procedures.

The most common approaches are hierarchical task analysis (HTA) and cognitive task analysis. In hierarchical task analysis, the task description is broken down into sub-tasks or operations (Kirwan & Ainsworth 1992). HTA has been applied with much success to surgical training (Arnold & Farrell 2002) and error analysis in endoscopic surgery (Joice et al 1998). Box 2 shows a section of a task analysis of a laparoscopic cholecystectomy (Joice et al, 1998). Tasks may be described at different levels of detail according to the demands and purpose of the analysis.

Cognitive task analysis aims to describe the process of thinking, decision making and problem-solving that underlies an intellectual task. Usually those carrying out such tasks talk through the process and supplement their accounts with information gathered from structured interviews. Cognitive task analysis has been used to develop the teaching of technical skills in a surgical skills laboratory (Velmahos et al 2004), to design computerised patient records and decision support tools (Kushniruk et al 1997) and to study clinical decision making in anaesthesia (Weinger & Slagle 2001). Cognitive task analysis requires a great deal of skill on the part of both the analyst and the clinician or worker. The ability to reflect and dissect one's own decision-making process can be enormously difficult. Task analyses may be supplemented by a timeline when timing or task allocation is particularly critical. This has been applied to diagnosis in telemedicine (Shah et al 1997) as well as to laparoscopic surgery (Payandeh et al 2002). Finally, integrated task analysis spans both physical and cognitive tasks. This is particularly important in healthcare but, as yet, has not been attempted.

Box 2: An example of Hierarchical Task Analysis – adapted from Joice et al.'s (1998) Task Analysis of the Dundee technique of laparoscopic cholecystectomy



Another means of tackling this problem is the use of the skill-rule-knowledge framework applied by Rasmussen (1986). This predicts errors based on the automaticity achieved by the operator in the task. This has been discussed with regard to healthcare by Felciano (1997). For example, a misperception could lead to confusion of patients' charts and result in a rule-based error or mistake where one would carry out the wrong rule under these erroneous circumstances.

To validate a task analysis, a different data collection methodology is often employed. For example, a task description may be created through observation and then validated with a structured interview in which the expert may work through the task description with an operator to confirm its validity. Task analysis may also be validated by checking the analysis with experts who were not involved in its generation.

4.3.3: Task Simulation Methods

Task simulation methods build on task description and analysis to consider how the performance of a task might change in different contexts or when carried out in specific circumstances (for instance under stress or time pressure) or in combination with other tasks. There are a number of task simulation methods with self-explanatory titles including table-top analysis, walk-throughs and talk-throughs of specifically developed scenarios. There seems to be no published use of these three methods in the health-care sector – which is regrettable as these methods are both cheap and simple. However, some similar techniques such as 'think-aloud' and the use of 'vignette' scenarios for training and evaluating decision-making have been applied in medicine (Wolf et al 1996). Ironically, the type of simulation most employed in healthcare is the most difficult and most expensive though this is usually in the context of training rather than analysis. Simulations of anaesthesia, surgery and other clinical practices have been used extensively for the training and assessment of individual skills and team performance (Satava, 2001; Jha et al , 2000; Howard et al 2003 Reznek et al 2003).

4.3.4: Human Error Identification and Analysis Techniques

Human error analysis is, ultimately, the primary aim of human reliability assessment. Most of the error analysis techniques (as shown in Appendix 4) are based on an initial task analysis and perhaps also a task simulation to identify a list of the potential errors that could occur associated with this task. There are a few exceptions to this. For example, in Barrier Analysis, the errors need to have been pre-defined by the HRA expert and the group of clinicians are then required to analyse the barriers preventing this error and identify potential improvements.

Human error identification and analysis techniques are more diverse than task analytic techniques. Some rely primarily on expert judgement and group discussion and are relatively loosely structured (e.g. FMEA McDermott et al 1996). Others (e.g. SHERPA, Embrey 1986) involve highly structured taxonomies that require the analyst to apply 'external errors modes'; these are a list of generic descriptive terms which define ways in which a task can fail (e.g. task not done, task done too early, task done too late). Human error analyses also vary in the nature of the task description that precedes them. For instance, SHERPA and HAZOP both require a well-defined task description to identify errors, SHERPA specifically requires a hierarchical task analysis, whereas HAZOP (Kletz 1999) is more flexible regarding the nature of the initial descriptive technique.

Some of the methodologies also take performance shaping factors (know in healthcare as contributory factors) into account. There are situational, contextual or environmental factors that may impact on an individual or system and make errors more or less likely to occur. This may be implicit in the method – such as those techniques that require group discussions (FMEA, HAZOP) – or explicit, where a list of potential impacting factors is provided as part of the technique (e.g. SHERPA). To prepare or to implement these requires a certain amount of expertise in human factors and, in the case of the computerised techniques, a high level of programming skill. As an example of a commonly employed human error analysis method, a segment of an FMEA of a drug delivery systems is shown in Box 3 (Burgmeier 2002).

Box 3: The analysis of a failure mode in the blood transfusion process (adapted from Burgmeier 2002)

Failure Mode	Cause of Failure	Effects of Failure	Design Action (Solutions)	Validation and Monitoring
Two people do not always check order entry for blood products	• Immediate patient care elsewhere is often more important • Nurses do not fully understand the consequences of a decision not to enter an order when they give priority to a patient elsewhere • Nurses do not fully use each other as resources • Order enterer prefers to 'get things done' rather than follow process carefully and correctly • Current policy is not explicit that two people must check the order	• Wrong patient gets 'stuck' • Waste of personnel and resources • Delay in treatment to appropriate patient • Ties up scarce blood resources • Increases patient's level of risk • Increases length of stay • Demoralises people involved (I could have harmed someone!)	• Blood specific order form used by all departments and on computer screen that is completed by physician. Training on use of form will be given to everyone participating in blood transfusion process. Order form faxed through to Blood Transfusion Service and double-checked against computer entry. In the longer term, physician will enter order directly into computer	• Data are collected on variances of paper and computer entries. Incidents of documented variance are recorded and analysed • Manager will discuss variances with staff as necessary

It should be noted that some of these techniques (notably HEART, SHERPA and THERP) also incorporate a phase to quantify the human error probabilities whilst others may be merged with human reliability quantification techniques as described in the following section.

4.3.5: Human Error Quantification Techniques

HRA may be considered complete at the end of the analytical phase if only the identification is of concern. The goal of human error quantification is to produce error probabilities. In some cases, these are applied in structures to estimate an overall likelihood of adverse consequences – for example in fault tree analysis or event tree analysis. These are then used as part of probabilistic risk assessment (PRA) or probabilistic safety assessment (PSA) to provide a complete picture of both human and non-human (eg. equipment) failures. Such techniques have been applied in this way to anaesthesia (Paté-Cornell et al 1997, Paté-Cornell 1999). Quantification, if it can be achieved, clearly offers the promise of more accurate prediction and ultimately safer systems. It is inbuilt to some techniques, such as FMEA, but may also be used in conjunction with others, such as influence diagrams and barrier analysis. In high-risk industries, predictions on the probability of each error based on known error data or experts' opinions. Performing human error quantification ensures that the management have a good understanding of, and adequate control over, the risks in their work.

Quantification of error is the most difficult aspect of HRA. Assigning numbers to necessarily uncertain events, that is the expected probability of an unknown individual making an error, is an enormous challenge. For example, suppose that a technique has identified that a crucial potential error such as 'patient information not communicated adequately from one member of staff to another'. Given the varying circumstances in which this might occur, it cannot be easily predicted experimentally and would probably require formal observation over a substantial period of time to fully map its occurrence. These difficulties are compounded errors that occur very rarely or those that cannot easily be observed such as errors in decision making. Nevertheless some hospital tasks, such as blood transfusion, are highly structured and the quantification of errors probabilities would seem to be eminently feasible.

Collection of error frequency data ideally requires high numbers of descriptive incident reports and systematic observations, which require objective human factors methods of error categorisation and frequency assessment. As these data are rarely available in a usable form, most quantification techniques rely on the views of subject matter experts led by a human reliability analyst with knowledge of the specific quantification mechanism being used. In this case, there are various techniques to support the subject matter experts. Such techniques range from the 'paired comparisons' technique involving the collation of a number of individuals' estimations of which of a pair of errors is the more probable, to the more structured quantification aspect of HEART (Williams 1986). HEART uses an estimation of error based on the familiarity and complexity of the task modified by estimates of the influence of 'error-producing conditions' such as time shortage, stress or ambiguity in the required performance standards. Although many of the human error quantification techniques (e.g. THERP & HEART) rely on expert judgement to assign probabilities of error to the task being performed, it has been found that the reliability and accuracy of these judgments made by trained human factors personnel is incredibly accurate (Kirwan et al 1994).

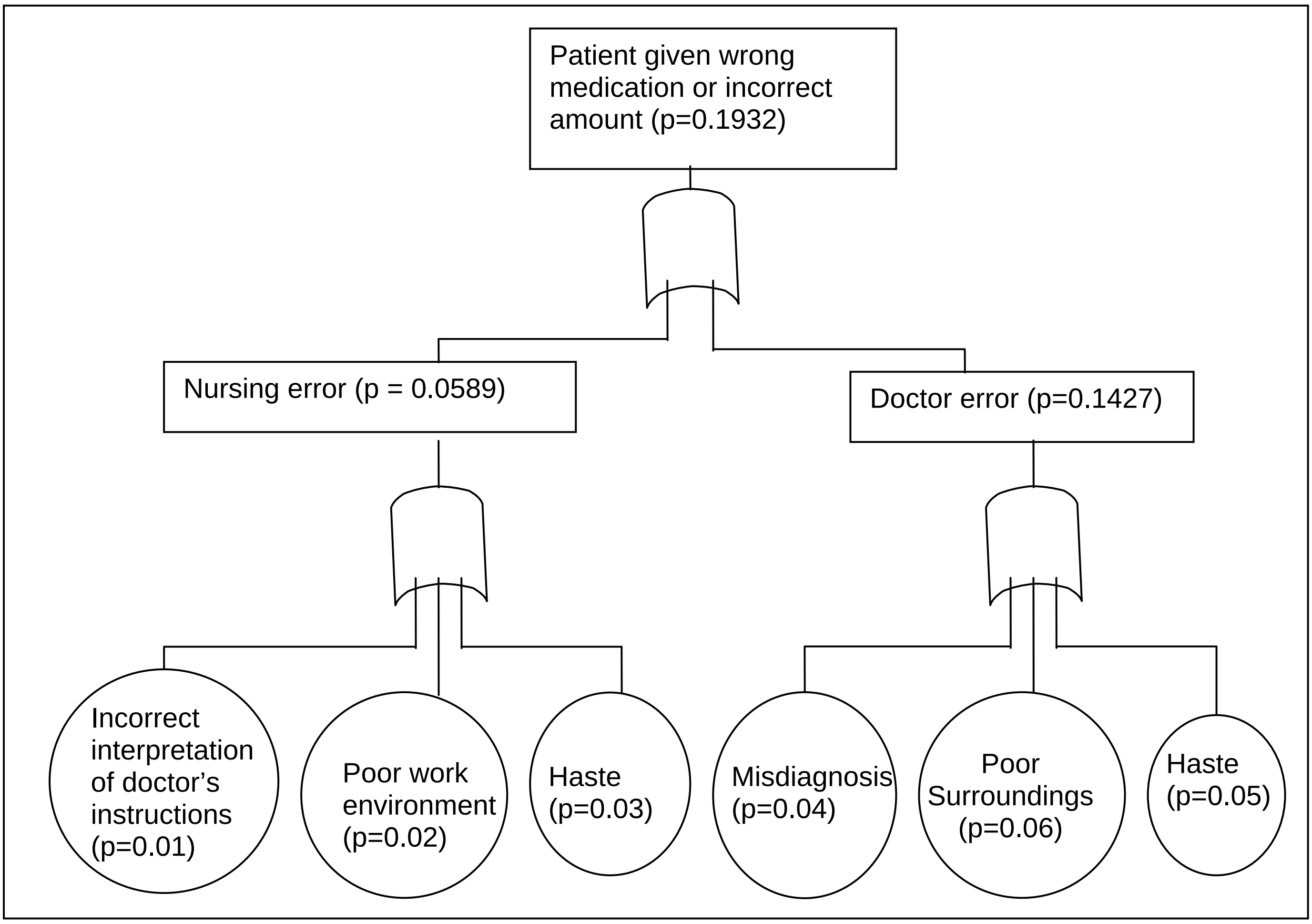
Quantification is usually based on either fault trees or event trees, which provide the basis for quantification. An example of a fault tree is shown in Box 4 while the numbers in the example are entirely fictitious, the diagram shows how physical and human error probabilities can be combined using logical OR gates to provide an overall estimation of an adverse outcome. These use Boolean logic where probabilities are assigned to events, these are inputted to a gate and result in the calculation of the overall probability for the top event. The full calculations are shown in Dhillon (2004) and a further explanation of fault and event trees are given in Appendix 5.

Hannaman (1984) has expanded Rasmussen's skill-rule-knowledge concept in the method Human Cognitive Reliability (HCR) to use performance time established through simulation or expert judgement to work out probability of a non-response within a time window for each of the three modes of behaviour. Whilst this has only so far been applied in the nuclear industry and is a complex tool, conceptually HCR with some development has the potential to be used in healthcare.

HRA is particularly rich in human error analysis and healthcare has, so far, been cautious about applying them. Most analyses have gone little further than the relatively simplistic incident decision trees. HEART and THERP (Swain & Guttman 1983), for instance, are both well-validated error analysis and quantification techniques and whilst they have been primarily applied in the nuclear industry, the detailed level of behaviour that they have considered makes them at least conceptually useful to apply in healthcare.

As it can be seen, only a few applications of human error quantification have been attempted – probably due to the difficulty of the task. Nevertheless, it is important to iterate that such concepts can be applied and it should be feasible to adapt the more complex error quantification methods – such as HEART, THERP and SLIM (Embrey et al 1984) from their natural industrial tasks to healthcare problems. Readers need to be aware that THERP is rather time intensive and complex to complete, compared with HEART and SLIM which are conceptually less intensive. However, there are aspects of THERP that users may want to select for their own purposes.

Box 4: A Fault Tree applied to medication error (adapted from Dhillon 2004)



5: Application of HRA method in healthcare – Barrier Analysis

5.1: Rationale for application

Following the review of techniques, the next phase was to try out one of the techniques in a specific healthcare area. Whilst it would be ideal to develop error reduction techniques which could potentially identify error reduction strategies in all aspects of the patient care process we had to select a technique that was feasible to conduct for the second phase of the research project.

Therefore we narrowed the development of a technique in two separate ways:

a) by choice of specific department
b) by choice of specific systems applicable within this department

It was desirable to choose just one department as it seems more feasible to ensure support to the work if only one group of people are involved rather than relying on support across a number of different departments.

Also, by focussing on the work of one department, it seemed more feasible that conclusive results could be observed.

The Accident & Emergency Department of St. Mary's Hospital was chosen as the department in which to conduct the study and to implement any potential solutions. On discussion with the department, they considered the medication process an issue that they would be interested in having analysed for error reduction potential.

On review of the methods identified in the literature, a short-list was produced as shown in Appendix 1 and therefore it was necessary only to select options for initial piloting within the A&E department. Table 2 shows the error reduction potential as assessed in a previous review (Woloshynowych et al, in press).

Table 2: Error reduction potential assessment of incident investigation techniques

Low	**Medium**	**High**
IDA (Influence Diagram Approach)	Tripod-BETA	Barrier Analysis
Change Analysis	STEP	MORT
	Fault Trees	RCA
	Events and Causal Factor Charting	Object-Z
	Accident Anatomy Method	Wheel of Misfortune

For this reason, one of the techniques with high potential was chosen to be applied to the problem area – that of barrier analysis.

5.2: Introduction to Barrier Analysis

Barrier Analysis is a technique used primarily by the nuclear and chemical process industries to reduce error by looking at the barriers which are put in place to protect vulnerable objects, from the hazard caused by the transfer of harmful energy (Trost & Nertney, 1995). Other techniques incorporating the same concept include 'Safety barrier function analysis' (Kecklund et al 1994), 'Accident Evolution Barrier Function' (Svenson 1991, 2001), 'Energy Barrier Analysis' (Rahimi 1986) and Safeguard

Analysis – (which was renamed for the healthcare sector; Dew, 2003). This can be interpreted in healthcare as placing a barrier to protect the patient from the risks of healthcare treatment. The term barrier can be inter-changed with the words control, defence or safeguard. It should be noted that barrier analysis is also provided by the NPSA and therefore barrier analysis could provide a major role in reducing error in healthcare in the future. (http://www.npsa.nhs.uk/rcatoolkit/resources/word_docs/Tools/Tools_Barrier_Analysis.doc).

5.3: What is Barrier/Safeguard Analysis?

Barrier analysis considers what safeguards are present in a process to protect vulnerable objects from harmful objects or actions. Examples include:

‘crash barrier’ which keeps opposing direction traffic apart even following the loss of directional control;

‘barrier cream’ which when applied provide skin protection from irritant chemicals;

‘Great Barrier Reef’ which protects the coastline from inundation of water during storm situations.

In an organisational context, these barriers are defined as:

- Physical – where a physical entity blocks the route of harmful energy to the vulnerable object, such as fences, cages or walls or a radiographer’s lead apron as well as the examples given above.
- Natural – where distance, time or placement is used to protect the vulnerable object from the harmful energy. Time and Distance provide a natural barrier to protect the earth from the searing heat of the sun; by the time, the sun’s solar radiation reaches the earth, it has cooled to a sufficient degree enabling life on earth to exist. Consider also the contraceptive method known as ‘the rhythm method’, this works by relying on the fact that due to cyclic characteristics of the female reproductive system, there will be no egg to fertilise during the time at which the sperm is alive within the reproductive tract, hence providing a barrier against pregnancy.
- Human Action Barrier – where human action either makes the hazard safe, removes the vulnerable object from risk of harm or provides or reinforces other types of barriers. These could involve firemen putting out a fire, security-guards or police removing dangerous people from a public area.
- Administrative Barrier – where rules, regulations, guidelines and training can provide the barriers that may not be provided elsewhere. These can include road-traffic signs and lights to ensure the safety of traffic flow – as well as driving licensing to ensure the road-users are competent in understanding such regulations and Laws that reinforce all of these concepts.

The second issue of barrier analysis is to consider the respective strength of each barrier – that is, the degree to which they provide protection from the harm for the vulnerable parties. This strength must take into account, the effectiveness – can these barriers be easily broken? And the extent to which the barriers are in place – i.e. do they always work or just when implemented. For example, a cage is a strong barrier protecting the public from dangerous animals – but if the door is left open, then it is a weak barrier. Human action is not always reliable as we all prone to error and so human action and administrative barriers, such as Rules and Regulations, are easily broken both deliberately and accidentally and therefore provide a weak barrier; however, this is strengthened if supervision and monitoring is provided. Therefore in healthcare, where care is provided by a variety of people at multiple points in a patient's pathway it is important that a variety of barrier types are implemented to minimise error likelihood.

We also introduced the concept of 'barrier-breakers'. This is where circumstances prevent or diminish the effectiveness of the barriers. For example, a crash barrier is no longer effective after someone has crashed through and broken it; barrier cream may be washed away. Rules and Regulations are regularly broken by those who are ignorant of them or by those who see advantage in disregarding them. Therefore, it is also necessary to consider the strength of the barrier-breakers. 'Would they always succeed in making the barrier ineffective?'

Once barriers and the barrier-breakers and their respective strengths have been assessed, it is then possible to see what improvements are required. These improvements can reinforce current barriers, diminish the effects of barrier-breakers or may be completely innovative methods of reducing the risk of harm. From this point, it is necessary to look at the cost and feasibility of the improvements as well as identifying those responsible for initiating these improvements.

Barrier Analysis is flexible enough to be used both retrospectively, to examine a particular incident, and prospectively, to examine a specific process by looking at the possible risks associated with it and what barriers are currently in place to protect the patient, staff or equipment in question. In both cases, the barrier analysis technique relies on drawing together opinions from a team representing all the different roles relevant.

5.4: Process of Barrier Analysis

The process of barrier analysis consists of the following stages:

A. Identify the key problem for barrier analysis
B. Identify a team leader
C. Identify the relevant individuals
D. Preparation for collecting the data
E. Train and perform barrier analysis
F. Present the results to prioritise the changes
G. Implement the changes

A. Identify the key problem for barrier analysis

To interpret how Barrier Analysis would be applied to the medical sector, it should be perceived as 'safety is impaired when, through action or inaction of healthcare providers, harm reaches the patient'.

Barrier Analysis should generally be approached when there is a specific hazard or concern that needs to be addressed. This can be identified using systematic techniques such as task analysis, as described in the task description part of the literature review above or through brain-storming and discussions. Problem areas can also be identified during incident investigation and analyses such as the NPSA's Root Cause Analysis process or the London Protocol (Taylor-Adams and Vincent 2004).

The problem or hazard should be phrased in a way that is clear to all the relevant personnel and needs to be described in enough detail to ensure that the resolutions are useful and not too generic.

Likewise, it is inadvisable to make the hazards so specific that there is little room for creativity and flexibility in terms of the improvements to be suggested. For example 'Nurse dispensing drugs into the wrong container resulting in drugs being administered via the wrong route' may pose a serious risk; however, for this risk the barrier analysis would focus specifically on the nurse dispensing/drug preparation phase and may not bring as much depth into the administration phase – leading to the eventual harm being caused. Only if all the relevant hazards are to be covered should a barrier analysis require this level of detail.

B. Identify a team leader

The team leader should ideally be someone independent of the physical and organisational process under investigation; for example a clinical risk manager, health and safety manager or an expert in clinical governance depending on who is most appropriate for the issue. The leader needs to have skills in leading and facilitating team discussion. They will be responsible for setting up the barrier analysis sessions and training, supporting the team, providing a central point for communications and ensuring timely progress and conclusion of the barrier analysis.

C. Identify the relevant individuals

The next phase is to identify the individuals to be involved in the barrier analysis. This should include all staff which have a role to play in the whole process or procedure related to the problem identified for barrier analysis. Everyone should be encouraged to contribute to the analysis. These could be from all areas impacting on the process – such as doctors, nurses, pharmacists, assistants, porters, receptionists or even the patients. Ideally staff with a range of experiences should be included: those with the most experience will be able to describe scenarios where barriers have both succeeded and failed and are the most likely to be able to suggest feasible solutions; whereas less experienced staff may be able to identify issues related to any difficulties with the learning and training of the procedure. Because they are not constrained by paradigms of work, they may be able to help generate more effective solutions.

D. Preparation for collecting data for barrier/safeguard analysis

It is the team leader's responsibility to prepare the materials for the barrier analysis. For the most part, this involves developing training materials and the materials required to collect and collate data. The materials required consist of: a comprehensive explanation of the purpose and methods of barrier analysis including examples of the relevant terms and the types of barriers (including fully worked examples from within and outside the medical context); a barrier analysis table ready for data collection – comprising of a sheet with entitled 'dangerous occurrence' at the top and the following columns: 'barriers', 'barrier strength', 'barrier-breakers', 'strength of barrier-breakers' and 'improvements'. These columns could be on separate sheets as illustrated in tables 3-5.

If participants are likely to know something of the feasibility and management issues surrounding the cost implications of improvements and persons responsible for implementing such improvements, columns for these could also be added. The NPSA website has some background and data collection forms for both prospective and retrospective barrier analysis (www.npsa.nhs.uk).

How data are collected will depend on the practicalities of a particular unit. It may not be practical to arrange a meeting with all the necessary staff. Therefore, it is likely that barrier analysis training and data collection would be performed partly in teams and partly using individual structured interviews. Other issues to consider when selecting the most appropriate method is to ensure that all members of the team will be able to express their views and that the process is not dominated by any one individual. Thus it is important that the team leader has good facilitation skills.

E. Train and perform barrier/safeguard analysis

The first step is the training – which involves explaining the purpose of barrier analysis, the method and finally the hazard to be considered. This may be in a group training course or as individual one-to-one tuition. In all cases, it is important to emphasise that the overall goal of the barrier analysis is to examine the process and its safeguards to prevent error (and not to look at errors that may have already occurred, unless a retrospective barrier analysis is being conducted). Sensitivity to the participants' experience is important and careful use of terminology is advised to reassure them that no blame will be assigned as a result of this.

Barrier Analysis can be carried out using questions to stimulate the ideas to fill the barrier analysis table such as those shown in Box 5. After each section, it is worth returning to the first section on Barriers to see if any new barriers have been identified.

Box 5: Specific questions for the various stages of Barrier analysis

1. Barriers / Safeguards
Consider the hazard / problem in question:
What barriers are in place to ensure this problem does ***not*** *occur? What barriers are in place to ensure this problem is identified and corrected before causing harm to the patient? What barriers support to correct the problem so it does not result in harm to the patient?*

2. Type of Barrier
What type are the barriers identified in 1? Are they physical, natural, human action, or administrative? Can you think of any examples of each type of barrier for this problem?

3. Strength of the Barrier
For each of the barriers identified rate whether it is strong/medium/weak; consider the following questions to help you decide on the strength of each barrier:
How effective is the barrier at preventing you from causing harm? How effective is the barrier at preventing harm for someone who is less skilled than yourself? How effective is the barrier at preventing harm for someone who is less vigilant than yourself? How effective is the barrier at preventing harm for someone who would deliberately want to cause harm to the patient?

4. Barrier-Breakers
Consider the factors that would make the barriers fail:
What factors make it more probable that the barrier will fail? What other factors would make it more probable that the problem would occur and/or cause harm to the patient?

5. Strength of Barrier-Breakers
For each barrier-breakers identified in 4, rate whether it is strong/medium/weak:
Do these barrier-breakers always cause failure of the barrier when they are present? Are these barrier-breakers always evident in the system to risk preventing the barrier from working? Do these barrier-breakers prevent identification and correction of the problem thus ensuring harm will reach the patient?

1. Improvements
What changes could remove the problem from the system? What factors would reduce the risk caused by the hazard? What new barriers could be provided / designed / developed to ensure this hazard does not occur? What new barriers could be provided / designed / developed to ensure that harm from this hazard does not reach the patient? What changes could strengthen the effectiveness of the current barriers? What changes could remove or reduce the impact of the barrier-breakers?

2. Cost implications
For each of the improvements, consider the financial implications.
What would be the financial cost of this improvement? HIGH / MEDIUM / LOW
What would be the cost in terms of time and effort of this improvement? What additional support would this improvement require to ensure that this improvement works?
3. Persons responsible
For each of the improvements, identify who could be given the responsibility to initiate the change or improvement. This could be a group or an individual role within the organisation.

F. Present the results and prioritise the suggested changes

Once the data has been collected and collated, it is necessary to present the results in the form of the completed barrier analysis table to the individuals and teams who contributed to it. This may also include those who can make the decision whether to follow up and address the changes. This may generate further discussion of additional ideas for improvement. Once the changes to take place have been agreed and the costs considered, then individuals responsible for implementing these changes will be identified. It is important to put the planned change on the agenda to ensure that the changes will be implemented.

G. Implement the changes
Finally, the results have been collated and analysed in terms of their feasibility and it is necessary to act upon the results in the form of implementing positive change. Strategies and measures may need to be put in to place to enable the change to take place and that the costs have been approved. It may be useful to identify a separate person to follow-up on progress and check for any difficulties.

5.5: Barrier Analysis: a practical example in Healthcare

5.5.1: Barrier Analysis Preparation

We chose to focus on the medication process of giving oral drugs in majors due to the following reasons: the divergence of the tasks between the various areas in the A&E department; differences in routes of administration; for simplicity; and due to it being a commonly used and easily observable process.

First, a hierarchical task analysis of the medication process in A&E was carried out through observation of the process and then verified with one of the nursing staff – as shown in Appendix 6.

Following this, a selection of error guidewords (Taylor-Adams & Kirwan 1994) were applied to the process to identify possible deviations from the normal practise. Once any duplicated events had been removed from the list, this gave a list of 65 events which could possibly be hazardous occurrences as shown in Appendix 7.

This list of events were presented to a group of 4 senior A&E staff (2 consultants and 2 modern matrons) by the research team to identify those that were considered

a) The 3 most frequent
b) The 3 most severe

To ensure the opinions of all staff were captured, the events that had more than one member of staff selecting them as the important issue were chosen for the barrier analysis technique. This resulted in 6 events :-

- Administration completed correctly but not communicated orally or written on the drugs chart
- Prescription process carried out too early (i.e. before examining patient or patient's notes)
- Prescription poorly written
- Drug written on prescription of wrong patient
- Wrong drug prescribed
- Incorrectly prescribed drug administered

5.5.2: Barrier Analysis Method

The risk of 'a medication prescription not checked by a nurse before being administered by a nurse' was additionally identified by the senior staff as a concern for the A&E department and therefore was chosen for barrier analysis through the process of task analysis, error analysis and group discussion. To narrow the scope of the process, all participants were asked to consider this event as occurring in the prescription and administration of oral drugs in 'majors'.

A human factors expert (ML) took the role of team leader. Team members were selected from the A&E staff involved in the medication process – in this case 2 A&E Consultants, 1 Registrar, 1 Matron, 3 Emergency Nurse Practitioners and a Senior Staff Nurse.

Training and data recording materials were prepared and the team were trained either on a one-to-one basis or in groups depending on availability. Immediately following the training, the team members were presented with the medication administration problem for barrier analysis and were asked to identify the barriers, the barrier-breakers, their respective strengths and overall suggestions for improvements. Then each individual had the opportunity to see what other members of the team had contributed to see if this generated further ideas. This was a re-iterative process until no further ideas were elicited. The ideas elicited for each part of the barrier analysis process are shown in the tables below. The completed data set was presented to the group members for identification of cost implications and the prioritisation of suggested improvements.

5.5.3: Barrier Analysis Results

Table 3 shows that whilst participants mostly generated original barriers/safeguards that others had not mentioned. When there was agreement regarding the barrier, there was often discrepancy between the opinions on the strength of barriers relating to policies or specific safeguards regarding the prescription procedure. The numbers in column 2 indicate how many participants identified that particular barrier.

Table 3: Barriers or safeguards to prevent a dangerous occurrence: Prescription not checked by nurse before administration

BARRIERS / SAFEGUARDS IDENTIFIED BY STAFF	**No. of staff**	**STRENGTH**		
		Strong	**Medium**	**Weak**
ADMINISTRATIVE BARRIERS				
Codes and Procedures				
Nurse's code for administration – the 5 R's §	2	✓		✓
Procedures	2			✓✓
Policies	4	✓	✓	✓✓
Requirement to look in policy booklet	1			✓*
Proceduralised action with prescription				
Procedure of writing on prescription / signing off	3		✓	✓✓
Culture	1			✓*
Software design intervention				
Electronic pop-up warning on a computer system	1	✓		
HUMAN ACTION BARRIERS				
Supervision / Co-working				
Supervision by Senior colleagues	2			✓*✓*
Any other colleague	2		✓✓	
Patient questioning	1			✓*
Training	1			✓
Doctor training – where nurses are responsible for teaching them and therefore are more likely to check their own procedures	1	✓		
NATURAL BARRIERS				
PHYSICAL BARRIERS				
Environment design				
Drugs physically locked away where you can't get them before you can prove to another member of staff by showing the prescription	1	✓		

§ the ***5 R's*** refer to the 5 Rs of medication administration: (1) the right medication (2) be given to the right patient (3) in the right dose (4) by the right route (5) at the right time.

* judged as 'weak' because doesn't happen; would be considered as 'strong' if it did

Some of the barrier-breakers in the Table 4 correspond to the barriers or safeguards listed in Table 3, whereas others were generated by considering what factors could increase the likelihood of the problem. The barrier-breakers generated have been organised using the framework described in the London Protocol for the analysis of critical incidents (Vincent et al., 1998; Taylor-Adams and Vincent, 2004) and show a wide range of contributory factors. Again the perceived strengths of the barrier-breakers are often discrepant though for the most part there is very little duplication in the generation of barrier-breakers.

Table 4: Barrier-breakers that could provoke prevent a dangerous occurrence: Prescription not checked by nurse before administration

BARRIER-BREAKERS /SAFEGUARD-BREAKERS	**No. of staff**	**STRENGTH**		
		Strong	**Medium**	**Weak**
ORGANISATIONAL AND MANAGEMENT FACTORS				
Poor culture	1	✓		
Poor role modelling	1	✓		
Staff unavailable / short staffed	1	✓		
No procedure in place	1			✓
Poor training	1	✓		
Poor method of training	1			✓
Poor training on the protocol and uncertainty about its content	1			✓
WORK ENVIRONMENT FACTORS				
Busy department	2	✓	✓	
Time pressure	1	✓		
Time constraints – where the prescription has been written up but not passed on to the nurse	1			✓
Too many patients for each nurse	1	✓		
TEAM FACTORS				
Unfamiliarity with other staff's experience (eg. Who is it safe to trust?)	1		✓	
Poor communication / Misunderstanding between person prescribing and administrator	2	✓		✓
INDIVIDUAL (STAFF) FACTORS				
Inexperience of staff	1		✓	
Unfamiliarity with the policy	1			✓
Erroneous assumptions based on experience	2	✓	✓	
Learning by poor examples	1		✓	
Personality (eg. Dominant senior intimidating junior)	1		✓	
Over-confidence	1	✓		
TASK FACTORS				
Resources and documentation unavailable	2	✓		✓
Illegibility of prescription	1	✓		
Poor software design	1	✓		
PATIENT FACTORS				
A sick patient who needs the treatment now!	1			✓

Table 5 displays the improvements suggested by the staff, their related costs and the group or individuals responsible for putting these improvements in place. Again, there is little duplication in the generation of ideas for improvements though there are similarities in terms of the broad categories of ideas. Most of the barriers that would be generated are either administrative or human action. When asked about responsibility the staff sometimes identified more than one section of the organisation, particularly those related to education and training or cultural/organisational change.

Table 5: Improvements suggested to prevent the dangerous occurrence: Prescription not checked by nurse before administration

IMPROVEMENTS IDENTIFIED BY STAFF	**No. of staff**	**Costs**			**Responsibility**				
		High	**Med**	**Low**	**NHS**	**Trust**	**Medical school / nurse education**	**Prof. body**	**Local staff**
Education and training									
Further training for doctors in administration practice	1		✓	✓✓		✓	✓✓		✓
Allow an experienced nurse to prescribe drugs (and thus shoulder the responsibility themselves!)	1	✓✓	✓		✓	✓✓	✓	✓	✓
Reinforce training	3		✓✓	✓			✓✓		✓✓
Supervision and Checking									
Supervised practise for junior staff	1		✓✓✓			✓			✓✓
Double-checking by senior colleagues	1	✓	✓	✓			✓		✓✓✓
Double-checking of charts by other members of staff	1	✓	✓	✓			✓		✓✓✓
Feedback									
Feedback on practice and near misses	2			✓✓✓		✓			✓✓
Rewarding good practice	1		✓✓	✓		✓✓			✓
Appraisals to address ‘undesirable’ attitude – e.g. Over-confidence	1			✓✓✓					✓✓✓
Resources									
More written resources – on frequently used drugs and doses / infrequently used drugs and doses	1			✓✓✓					✓✓✓
Up to date written resources	1			✓✓✓					✓✓✓
Greater availability of written resources	1		✓	✓✓					✓✓✓

Table 5 continued

IMPROVEMENTS IDENTIFIED BY STAFF	**No. of staff**	**Costs**			**Responsibility**				
		High	**Med**	**Low**	**NHS**	**Trust**	**Medical school / nurse education**	**Prof. body**	**Local staff**
Software Design									
Improved design of software systems	2	✓✓✓			✓✓	✓			
Cultural and Organisational change									
Change culture & behaviour	1		✓	✓✓			✓	✓	✓✓
Question everything	1			✓✓✓		✓	✓		✓✓✓
Increase staffing levels	1	✓✓✓				✓✓✓			✓

5.6: Barrier Analysis Discussion

The results of this study show that the barrier analysis technique is feasible for application in a healthcare setting. Even with a relatively small number of participants, a large number of barriers, barrier-breakers and improvements have been identified.

The ‘strength’ columns in Tables 3 and 4 show inconsistency in the perceived effectiveness regarding how strong the barriers or barrier-breakers are perceived. From previous studies on barrier analysis (Hollnagel 1999, 2003; Dew 2003; Dineen 2002) administrative barriers are generally considered to be weak as they are broken easily in the case of violations. However, in this study, many of the participants considered policies to be a strong barrier. This may be because they considered the fear of losing one’s job as a result of the hazard as giving this barrier ‘strength’ when, in reality, this is no stronger than any other rule or regulation. This has important implications for Trusts when considering what sorts of safeguards to put into place and in particular the associated costs, particularly when barriers which are expensive to maintain are mistakenly thought to be strong. One way to resolve this might be to include the advice of a human factors expert or someone experienced in barrier analysis.

The improvements identified by staff have been grouped into categories. Those relating to feedback or resources were considered to cost little or a moderate amount to be implemented. Staff agreed that changes to improve software design and increase staffing levels would be expensive. For the recommendations relating to ‘double-checking’ the associated costs span the full range from high to low cost. Improvements relating to the individual, such as ‘question everything’, appraisals for over confident staff, feedback, a change in culture and behaviour were judged to have low costs. This suggests that while the physical changes relating to software and staffing levels were thought to be costly, changes relating to individual action or behaviour were thought of as inexpensive.

Regarding who would be responsible for implementing the recommendations, ‘local staff’ was identified in all suggestions except software design. This highlights the importance of local involvement in any changes being implemented in their department, particularly changes relating to written resources.

The benefits of using barrier or safeguard analysis in healthcare are as follows: the technique is structured and therefore the participants are guided through the process towards obvious goals and outcomes. Secondly, it ensures opinions are collected from a large number of people and given equal representation in the final result. This is also a potential disadvantage as there is no prioritisation of suggested improvements or any measure of appropriateness of the suggestions – this can only be determined following the barrier analysis when taking into account the costs and feasibility.

There are both disadvantages and advantages of using either group or individual interviews. In a group setting, there is the advantage that ideas will be stimulated from person to person – but is the disadvantage that the views of some people may be over represented, while others are missed – thus emphasising the importance of using a team leader with strong facilitation skills. For individuals, there is the advantage of ensuring one person can be supported and encouraged to bring forth their own individual ideas but the disadvantage that they don’t have the opportunity to build on other people’s ideas and there may not be full agreement gained – for example, on the respective strength of each barrier. For this reason, it is considered worthwhile to interview individuals more than once – and present the newly-updated barrier analysis table on subsequence occasions until no further ideas are elicited.

The results were collected through individual interviews thus resulting the discrepancy between the numbers of people suggesting particular barriers (e.g. four people suggested policies as a barrier whereas only one person suggested culture) and the respective strength of the barriers (e.g. for policies, one person believed they were strong, one person believed they were medium and two people believed they were weak). For the most part, the strength of barriers could almost be defined in terms of its type (e.g. physical barriers are strong, administrative barriers are weak). However, the perception of the strength of the barrier is quite important – for example, supervision by senior colleagues would be considered strong if it occurred but weak because it did not (and therefore could not be relied upon), whereas supervision by any other colleague is considered of medium strength. Therefore, while these barriers are both human action barriers – seniority has an impact on the perception of their effectiveness.

The concept of barrier-breakers is a new addition to the technique of barrier analysis and has not been incorporated before either in industry or healthcare. This allows the individuals to generate the situational factors that will impact both on the barriers but also more global factors that are independent of the barriers and will increase the probability that the hazardous event will occur. For example, a sick patient or busy department could make many of the barriers in place fail independent of whether they were related to training or locked cupboards. Whilst it would be useful to know from an improvements-perspective which barriers are the weakest in relation to which barrier-breakers and the inter-linking between them, this has not been established within this project and could therefore be the focus of future research.

In terms of the improvements, it is notable that no obvious physical safeguards were generated. This is further evidence that healthcare relies heavily on rules and regulations to manage safety issues and when the system is pushed to the limit, the effectiveness of such barriers is clearly threatened.

Another benefit of the barrier analysis technique is that it is not based on lists of contributory factors as used by other error reduction techniques. These are the attributes of the environment, the task or context of the situation that may lead (or even pressurise) the worker to make mistakes. Because the method of barrier analysis is open-ended and does not predefine these factors, this allows for more creativity in the process therefore resulting in more focus on the improvements required in the specific environment rather than the more generic suggestions of 'improve safety culture' or 'improve staffing levels' that may be suggested by alternative techniques. Barrier Analysis allows for collection of the views of those working in the environment rather than selection of solutions from a list of pre-prepared suggestions thus providing them with a locus of control for management of their own department's problems. The only disadvantage of this is that the suggestions generated are potentially limited by the imagination of the participants – if there are only few subjects with the appropriate expertise, then there may be fewer suggested barriers and improvements – at worst, there may be no improvements suggested.

A particular limitation of barrier analysis is the time taken to collect data – for each subject, considerable thought is required to identify and assess all the safeguards and this can be a lengthy task. Training is an important part of the process and should not be taken lightly as the idea can be difficult to understand particularly emphasising the definition of a barrier as well as the consideration of all aspects in measuring its 'strength'.

6. Conclusions

The vast range of HRA techniques in high-risk industries suggests that the potential application of these techniques is very wide, encompassing design of equipment and procedures, organisation of work processes, the manner in which tasks are carried out and the wider, less obvious, factors that contribute to error and patient harm. HRA techniques might be used, for instance, in the design of surgical instruments; in decisions about the labelling of dangerous drugs; in designing a system of double checks for drug administration; in the design of work processes such as booking appointments or patient flow in the Accident and Emergency department; in identifying the factors that lead to high stress and liability to error in clinicians; and in the analysis of the range of factors involved in a serious incident and in the subsequent implementation of safety solutions across a clinical department or healthcare system. In all these examples the systematic application of specific techniques may bring a deeper and more comprehensive analysis than simple audit or common sense solutions, which frequently address the most obvious problem rather than the most important.

The field of anaesthetics has certainly taken the lead in applying established Human Reliability Approaches in healthcare and has now advanced to the stage where the conditions that impact on risk associated with an anaesthetist's performance have been weighted (Paté-Cornell et al., 1997) to the extent that problems from technical equipment availability to policy-making can all be assessed according to their impact on patient safety [Gaba, et al., 1987; Paté-Cornell et al., 1997). The application of advanced patient monitoring technology and alarms to identify significant internal changes indicating bleeding or infection (Gaba, et al., 1987) could also be seen as consistent with the principles of human reliability analysis.

We should note that few if any of these techniques have been subjected to formal evaluation. In one of the few reviews of HRA techniques Jeremy Williams began by saying 'It must seem quite extraordinary to most scientists engaged in research into other areas of the physical and technological world that there has been little attempt by human reliability experts to validate the human reliability assessment techniques which they so freely propagate, modify and disseminate' (Williams, 1985; Reason, 1990). By 1997 little had changed as Redmill wrote 'The techniques were developed independently, without an intention to standardise, or even to define, the boundaries between them' and suggested that there was a considerable need for standardisation, evaluation, consistency in terminology and exploration of the strengths and limitations of the various methods. Though this issue is being addressed in the areas of quantification through validation exercises of three of the most highly developed techniques (Kirwan 1996, 1997; Kirwan et al., 1997) healthcare, although coming late to these approaches, may in fact have much to offer because of the much stronger tradition of use of evidence, comparative clinical trials, evaluation and quantitative research.

Although overall, HRA should be viewed in terms of its main goal – i.e. to reduce errors, even in industry it can be seen to be lacking. Often the identification of errors or the estimation of the probability of their occurrence is seen as a sufficient end to analysis – without truly answering the question 'how can we prevent or reduce the probability of error?' Perhaps there is a misguided assumption that this is simple once the areas of concern have been highlighted – or perhaps this is such a challenge that even the HRA experts are reluctant to produce tools to develop it. Some techniques have addressed this challenge – through the means of acting upon the performance shaping factors that are known to promote error likelihood or through particular error reduction mechanisms such as those suggested by Kirwan (1994) in the HRMS method. These include concepts such as ‘increasing error predictability’, ‘enhancing error detectability’ and ‘increasing error controllability’.

However, it is most likely that, like industry, healthcare will eventually need to develop novel ‘domain-specific’ HRA tools – that are produced from the task analysis of specific healthcare tools in conjunction with contributory factors and using tailor-made healthcare specific quantification modules and validated with the incidents reported and categorised elsewhere. Such validation will therefore enhance the tool development as error reduction mechanisms can be assessed according to their ‘predicted impact’ on calculated error quantification as well as their observed impact on errors through the categorised incidents.

Barrier analysis is a relatively quick method of gaining the clinicians’ support and feedback on talking about errors within their environment and practice. It can be seen that the ideas that were evoked were consistent with many of the concepts recognised in human reliability; many of the ‘barrier-breakers’ were identical to the ‘contributory factors’ of the London protocol (Vincent et al 1998, Taylor-Adams and Vincent 2004) and the improvements suggested were typical error reduction strategies elicited in industry.

To conclude, this review has outlined some of the most frequently used and effective human reliability quantification tools used in other high risk industries and has attempted to discuss their applicability within a healthcare context. While some of the available techniques have already been used in certain areas of healthcare, there is considerable scope for other techniques to be applied to many aspects of healthcare. This review is an initial step in helping those interested to choose a suitable technique or tool to their field. The next step was to apply one of these techniques to a healthcare process. Barrier analysis was successfully adapted for healthcare and produced useful results. We also introduced a new concept, that of barrier- or safeguard-breakers to identify factors which in this case impose on the safe administration to include checking the medications.

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Appendix 1: List of techniques and acronyms

	Technique	**Acronym**
1	Accident Evolution Barrier Function Model	AEB
2	Absolute Probability Judgement	APJ
3	A Technique for Human Error Analysis	ATHEANA
4	Barrier Analysis	BA
5	Change Analysis	CA
6	Critical Decision Method	CDM
7	Cognitive Event Tree System	COGENT
8	Cognitive Reliability and Error Analysis Method	CREAM
9	Cognitive Task Analysis	CTA
10	Error of Commission Analysis	EOCA
11	Event Tree Analysis	ETA
12	Failure Modes Effects Analysis	FMEA
13	Framework Assessing Notorious Contributing Influences for Error	FRANCIE
14	Fault Tree Analysis	FTA
15	Generic Error Modelling System	GEMS
16	Hazard and Operability Analysis	HAZOP
17	Human Cognitive Reliability	HCR
18	Human Error Assessment and Reduction Technique	HEART
19	Human Reliability Management System	HRMS
20	Hierarchical Task Analysis	HTA
21	Influence Diagrams Analysis	IDA
22	Management Oversight Risk Tree	MORT
23	Paired Comparisons	PC
24	Petri-nets	-
25	Systematic human error reduction and prediction approach	SHERPA
26	Success Likelihood Index Methodology-Multi-Attribute Utility Decomposition	SLIM-MAUD
27	Skill Rule Knowledge framework	SRK
28	Sneak Analysis	-
29	Task Analysis	-
30	Tecnica Empirica Stima Errori Operatori	TESEO
31	Technique for Human Error Assessment	THEA

	Technique	**Acronym**
32	Technique for human error rate prediction	THERP
33	Time-line analysis	-
34	Technique for the Retrospective Analysis of Cognitive Errors	TraceR
35	Work Safety Analysis	WSA

Appendix 2: Search terms and hits

Search Term	**embase (1980-2003 Week 48)**	**medline 1996-Nov 2003 week 2**	**Erg Abstracts Online Accessed 4th March 2004 (database last updated October 24th 2003)**
Error	*	18944	6261
Error Explode - Error Focus - Analytical Error Focus - Diagnostic Error	69070	*	*
(limit to OVID full text available, abstracts, human, English language)	809	*	*
Cognitive Error	11	2	17
Error analysis	491	17347	103
Error consequence	5	2	
Error consequence reduction	0	32	
Error identification	38	16	35
Error pathway blocking	0	10	0
Error predictability	0	148	0
Error recovery	18	10	61
‘Error recovery enhancement’	0	0	0
Error Reduction	88	129	49
‘Error Reducing’	12	10	0
Human Error	389	414	845
‘human error analysis’	8	4	38
Human Error Assessment	1	0	13
Human Reliability	46	16	419
‘Performance shaping’	12	5	48
Iatrogenic disease	7282	2099	0
Iatrogenic disease AND safety	471	75	0
‘Medical error’	119	158	11
Medication Error	274	135	2
Patient Safety	1011	1890	27
Probabilistic risk	151	58	46
Probabilistic safety	21	1	102

Search Term	**embase (1980-2003 Week 48)**	**medline 1996-Nov 2003 week 2**	**Erg Abstracts Online Accessed 4th March 2004**
AAM	172	75	16
‘accident anatomy’	0	0	0
AEB	18	8	6
Accident Evolution	7	0	8
Activity sampling	11	32	6
APJ	58	54	1
‘Absolute Probability Judgment’	0	0	2
‘Absolute Probability Judgement’	0	0	0
ADSA	54	20	0
‘Accident dynamic’	1	0	0
ATHEANA	0	0	2
Barrier	37539	20212	130
Barrier analysis	16	0	2
‘Barrier Function’	3222	3555	7
CADA	100	47	0
‘Critical Action and Decision’	0	0	0
CAMEO	8	2	2
‘Cognitive action modelling’	0	0	0
CES	1053	727	12
‘Cognitive Environment Simulation’	1	0	4
‘Change analysis’	109	77	0
CIT	743	481	2
‘Critical Incident’	236	296	949
‘Critical Incident Technique’	70	62	937
CMA	853	371	0
‘Confusion matrix analysis’	1	0	0
COGENT	185	139	9
‘Cognitive Event Tree’	0	0	2
‘Cognitive Reliability’	4	4	20
‘Cognitive Task Analysis’	17	16	174
COMET	1686	1465	4
‘Commission event tree’	0	0	0
COSIMO	3	2	12
‘cognitive simulation model’	0	0	12
CREAM	5226	2147	13
CREAM error	19	9	*

Search Term	**embase (1980-2003 Week 48)**	**medline 1996-Nov 2003 week 2**	**Erg Abstracts Online Accessed 4th March 2004**
Consequence reduction	154	40	0
Consequence reduction error	0	0	0
CREWPRO	0	0	0
‘crew problem’	0	0	1
CREWSIM	0	0	0
‘crew simulation’	0	0	0
DYLAM	0	0	11
‘dynamic logical’	0	0	3
ECC	755	470	9
‘causal charting’	0	0	0
‘Enhancing detectability’	1	4	0
EOCA	23	12	0
‘Error of commission’	11	9	2
‘Fault Tree’	28	10	38
FMEA	12	14	9
‘Failure Modes’	115	96	24
Failure Modes Effects	5	3	1
FMEA error	*	6	*
GEMS	230	151	6
‘Generic Error Modelling’	1	2	6
HAZOP	11	8	33
Hierarchical task analysis	9	7	39
HEART	199393	120134	1928
HEIST	2	1	0
HEMECA	0	0	0
‘human error mode’	0	1	0
HRMS	238	142	1
‘Human Reliability Management’	0	0	1
IDA	731	486	7
‘Influence diagrams’	11	10	6
IMAS	118	75	1
‘Influence modelling’	0	1	0
‘Increasing controllability’	1	0	0
‘Increasing Predictability’	4	3	0
INTENT	5586	4204	244
INTEROPS	0	0	2
‘Integrated reactor operator’	0	0	1
Integrated Task Analysis	0	0	3

Search Term	**embase (1980-2003 Week 48)**	**medline 1996-Nov 2003 week 2**	**Erg Abstracts Online Accessed 4th March 2004**
ISA	429	284	27
‘Intelligent safety assistant’	0	0	0
JHEDI	3	2	7
MES	1295	730	8
Multi-linear event sequencing	0	0	0
MORT	676	22	4
‘Management oversight risk’	2	0	0
‘Murphy Diagrams’	0	0	0
Object Z	0	0	0
‘Object-Z’	0	0	0
‘Paired Comparisons’	235	137	28
Petri-nets	22	29	41
PHEA	113	45	2
‘Predictive human error’	1	0	1
‘Prospective human error’	0	0	0
PHECA	2	0	0
‘Potential human error’	7	4	6
PREDICT	52657	34130	1284
‘procedure to review and evaluate’	0	0	0
PRMA	7	3	0
‘procedure review matrix’	0	0	0
PSF	437	230	10
‘Performance shaping’	12	5	48
RCA	1357	762	8
Root cause error	137	43	48
‘Root Cause’	161	242	50
‘Root Cause Analysis’	22	72	23
SEAMAID	0	0	3
SCHEMA	1195	806	154
‘systematic critical human error’	0	0	1
SHERPA	31	17	6
‘systematic human error’	0	0	4
SIERRA	461	300	5
‘system induced error’	0	0	0

Search Term	embase (1980-2003 Week 48)	medline 1996-Nov 2003 week 2	Erg Abstracts Online Accessed 4th March 2004
SLIM	282	191	11
SLIM-MAUD	0	0	3
Success Likelihood	6	3	*
‘success likelihood index’	5	*	7
Sneak	21	13	2
SRK	200	173	11
SRK error	0	40	*
SRK error not lens	*	20	*
SRS	904	681	*
SRS-HRA	0	0	4
STEP	87049	50345	943
‘sequentially timed events’	2	0	1
SYBORG	1	0	6
‘system for the behaviour’	65	0	0
Talk-through	4125	8016	151
‘Task Analysis’	276	134	2692
TAT	4562	2984	5
‘Task Analysis Technique’	1	1	8
TAFEI	1	0	4
TALENT	350	306	26
Task analysis linked	0	1	0
TEACHER	4922	2140	102
‘technique for evaluating and assessing’	0	0	0
THERP	4	2	27
Timeline analysis	3	8	7
TOPPE	0	0	1
TOR	1078	594	1
‘technique of operations review’	0	0	*
‘operations review’	30	9	*
TRIPOD	191	72	3
Tripod beta	0	8	0
Verbal protocol	7	22	93
Walk-through	3830	7725	304
‘Wheel of misfortune’	2	0	0
WSA	60	17	2
‘work safety analysis’	1	0	5

Appendix 3: Techniques Identified

	Technique	**Technique full name**	**No of papers**	**Information**
1	AAM	Accident Anatomy Method	0	Described in Health Technology Assessment (Woloshynowych et al in press)
2	ACT	Accident Consequence Tree	1	Applied to furniture design (Aaltonen et al 1996)
3	Activity sampling	Not an acronym	10+	Described in Kirwan & Ainsworth (1992)
4	ADSA	Accident Dynamic Sequence Analysis	0	Cited in Kirwan 1998
5	AEA	action error analysis	1	Applied in chemical, nuclear industries cited in Suokas 1988
6	AEB	Accident Evolution and Barrier Function	10	Applied in hospital, aviation, water pollution (Svenson 1991, Svenson et al 1999, Gaba et al 1987, Svenson 2001, Svenson, & Sjostrom 1997 Svenson et al 1996)
7	APJ	Absolute Probability Judgement	3	Applied in computer and nuclear industries (Kirwan 1988, 1997, Waters 1988 in Sayers 1988), Humphreys 1988
8	ASEP	Accident Sequence Evaluation Program	2	Applied in Nuclear industry and military (Gore et al 1997, Habey et al 1994)
9	ATHEANA	A Technique for Human Error Analysis	2	Applied in nuclear (Dougherty 1998, Thompson et al 1997)
10	BA	Barrier Analysis	2	Applied in nuclear, human robots, aviation and medicine (Rahmini 1986)
11	CA	Change Analysis	4	Applied in aviation and health (Johnson 1976, Ferry 1981, Kepner & Tregoe 1976, Spath 2000)
12	CADA	Critical Action and Decision Approach	0	Cited in Kirwan 1998
13	CAMEO	Cognitive Action Modelling of Erring Operator	0	Cited in Kirwan 1998
14	CCA / CCT	Cause consequence analysis / cause consequence tree	0	Cited in Suokas 1988

	Technique	Technique full name	No of papers	Information
15	CDM	Critical Decision Method	2	Applied to white-water rafting guides, general aviation pilots, and emergency ambulance dispatchers (O'Hare et al, Hoffman et al, Crandall & Getchell-Reiter 1999 Wong 2004, Wong et al 1996, 1997)
16	CES	Cognitive Environment Simulation	2	Applied to nuclear power plant emergency operations (Woods et al 1988, 1990), Roth et al (1992a, 1992b)
17	CHEAT	Computerised Human Error Analysis Trees	1	Applied to process control (Basra & Kirwan 1995)
18	CIT	Critical Incident Technique	10+	Applied to medicine, manufacturing and nuclear (Gossen et al 2001, Thomas 2001, Orser & Oxorn 1994, Short et al 1993, Galletly & Mushet 1991, DeAnda & Gaba 1990, McKay & Noble 1988, Derrington & Smith 1987, Cooper et al 1984, Bradley 1992)
19	CM / CMA	Confusion Matrix Analysis	0	Applied to nuclear industry (cited in Kirwan 1997, 1998)
20	COGENT	Cognitive Event Tree	4	Applied to nuclear industry (Gertman 1993, Cooper & Fox 1998, Sanderson et al 1994, Fox & Cooper 1997)
21	COMET	Commission event tress	1	Applied to nuclear industry (Blackman 1991)
22	COOP	Case for control and operability	0	Applied to control software (Love 1999)
23	COSIMO	Cognitive Simulation Model	10+	Applied to nuclear and aviation industries (Cacciabue et al 1992a, b, 1990, 1989, Bellorini & Cacciabue 1991, Decortis et al 1993, Amat 1995, Grant 1995, Cacciabue & Kjaer-Hansen 1993, Masson 1989, Decortis 1993)
24	CREATE	Cognitive Reliability Analysis Technique	0	Applied to nuclear industry (cited in Ryan 1988)

	Technique	Technique full name	No of papers	Information
25	CTA	Cognitive Task Analysis	10+	Applied to aviation, medicine, submarine, rail (Seamster et al 1997, Hardinge & Masakowski 2000, Neerincx & Griffioen 1996, Grunwald et al (in press))
26	CREAM / Extended CREAM	Cognitive Reliability and Error analysis method	5	Applied to nuclear power plants (Hollnagel 1998)
27	CREWPRO	CREW problem solving simulation	1	Cited in Kirwan 1998
28	CREWSIM	CREW Simulation	0	Cited in Kirwan 1998
29	DARE	Distribution Analyzer and Risk Evaluator	1	Applied to Aerospace (Tulsiani et al 1990)
30	Deviation Analysis		1	Applied to ceramic industry; chemical industry; mechanical materials handling; packaging and paper industry (Harms-Ringdahl 2001)
31	DFM	Dynamic Flow-graph Methodology	1	Applied to nuclear software (Garrett & Apostolakis)
32	DREAMS	Dynamic Reliability technique for Error Assessment in Man-machine Systems	1	Applied to nuclear industry (Cacciabue et al 1993)
33	DYLAM	Dynamic Logical Analysing Methodology	10+	Applied with HERMES for Nuclear power plant (Cacciabue 1996)
34	ECC	Events and Causal Charting	0	Described in Health Technology Assessment (Woloshynowych et al in press)
35	Energy Analysis	Not an acronym	1	Applied in ceramic industry, chemical industry; mechanical materials handling; packaging and paper industry (Harms-Ringdahl 2001)
36	EMEA	Error Modes and Effects Analysis	1	Warning labels on all-terrain vehicles (Lehto 2000)
37	EOCA	Error of Commission Analysis	0	Cited in Kirwan 1998

	Technique	**Technique full name**	**No of papers**	**Information**
38	ET / ETA	Event Tree Analysis	10+	Generic description - Applied to chemical industry (Gressel & Gideon 1991), nuclear (Gertman 1993, Luckas et al 1986) and within THERP for Aviation maintenance (Ostrom, & Wilhelmsen 1998). Also Hollywell (1996), Heslinga (1984)
39	FRANCIE	Framework Assessing Notorious Contributing Influences for Error	3	Applied to airline maintenance (Ostrom & Wilhelmsen 1998, Haney 1999, 2000)
40	FMEA	Failure Modes Effects Analysis	10+	Applied to oil industry (Heising & Grenzebach 1989), space (Ray 1999), manufacturing (Luczak et al 2003), medicine (Benjamin 2003)
41	FMECA	Failure Modes and Effects Criticality Analysis	2	Applied generically (Yu et al 1998); applied to medicine (Williams & Talley 1994)
42	FSMA	Functional safety management assessment	0	Cited in Kirwan 1998
43	FT / FTA	Fault Trees / Fault Tree Analysis	10+	Applied in nuclear (Smith et al 1994) and chemical/ process industry (Hwang & Cheng 1992), space industry (Chen et al 1999) rail (Love & Johnson 1997) and medicine (Cromheecke et al 1999)
44	GAMEES	Graphical Modelling Environment for Expert Systems	1	Applied to medical advice (Bellazzi et al 1991)
45	GEMS	Generic Error Modelling System	6	Applied in nuclear industry (Embrey & Reason 1986), manufacturing (Luczak et al 2003), rail (Edkins & Pollock 1996) and air traffic control ~(Bes 1997)
46	HAZAN	Hazard Analysis	1	Applied in chemical industry (Roy et al 2003)

	Technique	**Technique full name**	**No of papers**	**Information**
47	HAZOP	Hazard and operability analysis	10+	Applied in chemical industry (Roy et al 2003), Water Science (Diaper et al 2001), biotechnology (Pettauer et al 1998), steel (Swuste et al 1997) and medicine (Redmill et al 1999)
48	HCR	Human Cognitive Reliability	4	Applied in nuclear industry (Yoshikawa & Wu 1999, Waters 1988)
49	HEART	Human Error Assessment and Reduction Technique	3	Applied in nuclear industry (Kirwan 1996, 1997a & b)
50	HEDOMS	Human Error and Disturbance Occurrence in Manufacturing Systems	2	Applied in manufacturing (Luczak et al 2003, Paz Barroso & Wilson 1999
51	HEMECA	Human Error Mode, Effect and Criticality Analysis	0	Cited in Kirwan 1998
52	HERA	Human Error in European Air Traffic Management	0	Known to author (http://www.eurocontrol.int/humanfactors_backup/hera.html)
53	HERAX	Human Error/ Reliability Analysis Expert	1	Applied to process control (Abdouni & Raafat 1990)
54	HERMES	Human Error Risk Management for Engineering Systems	1	Applied with DYLAM to nuclear industry (Cacciabue 1996)
55	HEROS	Human Error Rate Assessment and Optimizing System	1	Applied to nuclear industry (Richei et al 2001)
56	HRMS	Human Reliability Management System	1	Applied to nuclear and chemical industries (Kirwan 1997)
57	HTA	Hierarchical task analysis	10+	Applied to rail, aviation, nuclear power, surgery and nursing (Shepherd 2001, Kirwan & Ainsworth 1992)
58	HUMOS-PAD	Human Model Simulation of Plant Anomaly Diagnosis	1	Applied to nuclear industry (Wu et al 2001)

	Technique	Technique full name	No of papers	Information
59	IDA	Influence Diagram Approach	10+	Applied to chemical industry, (Cox et al 2003), environmental management (Varis et al 1993, Zhu et al 1998) and medicine (Magni 2000, Nease & Owens 1997)
60	IMAS	Influence Modelling and Assessment System	0	Cited in Kirwan 1998
61	INTENT	Not an acronym	0	Cited in Kirwan 1998
62	INTEROPS	Integrated Reactor Operator System	2	Applied to nuclear industry (Schryver & Knee 1987, Schryver 1988)
63	I-Risk	Not an acronym	0	Applied to rail (Hale et al 2000)
64	IRRAS	Integrated Reliability and Risk Analysis System	2	Applied to nuclear, chemical industry (Khan 1994)
65	ISA	Intelligent Safety Assistant	0	Described in Health Technology Assessment (Woloshynowych et al in press)
66	JHEDI	Justification of Human Error Data Information	3	Applied to nuclear and chemical industries (Kirwan 1997)
67	JLEPT		1	Applied to organisational management (Ransley 1994)
68	Job Safety Analysis	Not an acronym	1	Applied to ceramic industry; chemical industry; mechanical materials handling; packaging and paper industry (Harms-Ringdahl 2001)
69	Licensee Event Report	Not an acronym	2	Applied to Nuclear industry (Yeh & Evans; Pyy et al 1997)
70	MacSHAPA	Not an acronym	1	Applied to aviation, military, air traffic control and surgery (Sanderson et al 1994)
71	MAPPS / MPPS	Maintenance Personnel Performance Simulation (MPPS)	0	Applied to nuclear industry (cited in Ryan 1988, Kirwan 1997)
72	Markov decision processes	Not an acronym	1	Applied to computing (Johnson & Malek 1988) and medicine (Magni et al 2000)

	Technique	Technique full name	No of papers	Information
73	MEI	maintenance error investigation	0	Applied to aviation maintenance (O'Connor & Hardiman 1997)
74	MES	Multi-linear Events Sequencing	1	Described in Health Technology Assessment (Woloshynowych et al in press)
75	MESH	Managing Engineering Safety Health	1	Applied to aviation maintenance (O'Connor & Hardiman 1997)
76	Microsaint	Not an acronym	0	Applied to aviation (Laughery et al 2000)
77	MORT	Management Oversight and Risk Tree	10+	Applied to chemical, nuclear and space - described in Health Technology Assessment (Woloshynowych et al in press)
78	Murphy diagrams	Not an acronym	0	Cited in Kirwan 1998
79	OATS	Operator Action Tree Analysis	0	Applied in nuclear industry (Kirwan 1997)
80	OBJECT-Z	Not an acronym	0	Described in Health Technology Assessment (Woloshynowych et al in press)
81		Observation	10+	Described in Kirwan & Ainsworth (1992)
82	PC	Paired Comparisons	3	Applied to offshore industries; Oil and petroleum industry; Power plants - nuclear; Process control; Railways; Service industry (Kirwan 1994, Humphreys 1988, Comer et al 1985)
83	Petri Nets	Not an acronym	2	Applied to nuclear industry (Colombo & Saiz De Bustamente 1990); Offshore (Kontogiannis et al 2000) and process control (Amendola 1988)
84	PHA	preliminary hazard analysis	1	Applied to chemical industry (Gressel & Gideon 1991)
85	PHEA	Predictive Human Error Analysis	1	Applied to public technology (Baber & Stanton 1996)
86	PHECA	Potential Human Error Causes Analysis	0	Cited in Kirwan 1998

	Technique	Technique full name	No of papers	Information
87	PPA	Potential Problem Analysis	0	Cited in Suokas 1988
88	PRA	Probabilistic risk analysis / probabilistic risk assessment	5/ 10+	Described in Bier 1999, Kirwan 1992, Rasmussen 1985, Shlyakhter 1994 – used in nuclear industry (Rasmussen 1986, Dougherty & Fragola 1988 Forester 1995, Swain 1986), nuclear waste management (Liu et al 1989), using COGENT (Gertman 1993), CES (Woods et al 1988), HCR (Hannaman et al 1985, Wakefield 1988), ASEP – Luckas et al 1986, Samanta (1985), TALENT (Ryan 1988) Also used in process control (HERAX) (Abdouni & Raafat 1990) Used in digital systems – using DFM (Garrett & Apostolakis 1999). Applied in anaesthesia (Pate-Cornell 1997)
89	PREDICT	Procedure to review and evaluate dependency in complex technologies	0	Cited in Kirwan 1998
90	PRMA	Procedure response matrix approach	0	Cited in Kirwan 1998
91	PROF	PRediction of Operator Failure rate	1	Applied in process control (Drager & Soma 1988)
92	PROFAT	Not an acronym	1	Applied in chemical industry (Kahn & Abbasi 2000)
93	QMAS	Quality Management Assessment System	1	Applied in offshore industry (Bea 2002)
94	Questionnaires	Not an acronym	10+	Described in Kirwan & Ainsworth (1992)

	Technique	Technique full name	No of papers	Information
95	RCA	Root cause analysis	10+	Applied to nuclear industry (PYY et al 1997), aviation (Pedrali & Bastide 1997), telecommunications (Jones et al 1999), steel, pulp and paper, and petrochemicals (Vollmar et al 2001), medicine (Described in Health Technology Assessment (Woloshynowych et al in press)
96	RPDM	Recognition-Primed Decision Model	2	Applied to air traffic control (Mogford et al 1997, Hutton et al 1997)
97	Safecon		1	Applied in construction (Krishnamurthy et al 1991)
98	SCAP		1	Applied in chemical (Khan et al 2001)
99	(SCFM)	Safety Culture Failure Mechanism	2	Applied to nuclear industry (Kennedy & Kirwan 1995, Kennedy 1995)
100	SCHEMA	Systematic critical human error management approach	1	Applied to chemical industry (Livinston et al 1992)
101	SEAMAID	Simulation-based evaluation and analysis support system for machine interface design	3	Applied to nuclear industry (Yoshikawa et al 2001 Nakagawa et al 1995, 1996)
102	SHARP	Systematic Human Action Reliability Procedure	0	Cited in Hannaman & Spurgin (1984)
103	SHERPA	Systematic human error reduction and prediction approach	5	Described in Embrey 1987. Applied to public technology (Stanton 1997, Stanton & Baber 2002), Applied to Nuclear industry (Embrey 1986)
104	SIERRA	Systems induced error approach	0	Cited in Kirwan 1998
105	Simulations	Not an acronym	10+	Described in Kirwan & Ainsworth (1992)
106	SLIM-MAUD	Success likelihood index method using multi-attribute utility decomposition	10+	Applied to nuclear industry (Waters 1988) and assembly work (Granger & Chen 1994).

	Technique	**Technique full name**	**No of papers**	**Information**
107	SNEAK	Not an acronym	3	Applied to batch processes (Whetton & Armstrong 1994), nuclear industry (Hahn & Devries 1991) and computers (Hammer & Price 2001)
108	SRK	Skill, rule and knowledge base	10+	Described in Salminen & Tallberg 1996, Sanderson & Harwood 1988, applied to nuclear industry (Meshkati 1990, Meshkati et al 1995), manufacturing (Stahre & Johansson 1999) and all terrain-vehicles (Lehto 2000)
109	SRS-HRA	Savannah River Site HRA	0	Was an actual case study - in nuclear process industries (Waters & Duncan 2001)
110	STARS	Software Toolkit for Advanced Reliability and Safety	2	Applied to power plants (Nordvik et al 1995)
111	Statement analysis	Statement analysis	0	Applied to generic safety management (Whalley & Lihou 1988)
112	STEP	Sequentially Timed Events Plotting	1	Applied to offshore industry (Kontogiannis et al 2000)
113	Structured interviews	Not an acronym	10+	Described in Kirwan & Ainsworth (1992)
114	SYBORG	Simulation System for the Behaviour of the Operating Group	6	Applied in nuclear industry (Sasou et al 1995, 1996) and to electricity industry (Yoshimura et al 1997)
115	SYRAS	System Risk Analysis System	1	Applied to offshore structures (Bea 2002)
116	TAFEI	Task Analysis for Error Identification	3	Applied to public technology (Baber & Stanton 1996)
117	TALENT	Task Analysis Linked Evaluation Technique	2	Applied to nuclear industry (Ryan 1988)
118	Talk-through analysis	Not an acronym	10+	Described in Kirwan & Ainsworth (1992)
119	TAT	Task Analysis Tool / Task Analysis Technique	3	Applied to nuclear industry (Ainsworth & Marshall 1998), ship design (Vivalda 2000) and anaesthesia (Slagle et al 2002)
120	TCR	Time versus Cognitive Reliability	0	Applied to nuclear industry (Yeh & Evans 1986)

	Technique	Technique full name	No of papers	Information
121	TEACHER	Technique for Evaluating and Assessing the Contribution of Human Error to Risk	0	Cited in Kirwan 1998
122	TESEO	Tecnica Empirica Stima Errori Operatori	2	Applied to nuclear industry (Humphreys 1988, Waters 1988)
123	THEA	Technique for human error assessment	2	Described in Pocock et al (2001) Applied to air traffic control (Cartmale & Forbes 1999)
124	THERP	Technique for Human Error Rate Prediction	10+	Applied to nuclear industry (Bersini et al 1987, Kirwan 1988, Whittingham 1988, Cacciabue 1996), distribution (Pulat 1988), manufacturing (Pines & Goldberg 1992) and packaging (Granger & Chen 1994)
125	Timeline analysis		7	Described in Kirwan & Ainsworth (1992)
126	TOPPE	Team Operations Performance and Procedure Evaluation	1	Applied to nuclear industry (Beith et al 1990)
127	TOR	Technique of Operations Review	0	Described in Health Technology Assessment (Woloshynowych et al in press)
128	TRACEr		1	Applied to air traffic management (Shorrock & Kirwan 2001)
129	TRC	Time Reliability Curve / Correlation	1 / 1	Applied to nuclear industry (Yeh et al 1986, Dougherty & Fragola 1988)
130	Tripod – BETA	Not an acronym	1	Applied to petrochemical industry (Hale et al 2000)
131	Verbal protocols	Not an acronym	10+	Described in Kirwan & Ainsworth (1992)
132	Walk-through analysis	Not an acronym	10+	Described in Kirwan & Ainsworth (1992)
133	Wheel of Misfortune	Not an acronym	1	Applied to aviation and shipping (O’Hare 2000) Described in Health Technology Assessment (Woloshynowych et al in press

	Technique	**Technique full name**	**No of papers**	**Information**
134	WSA	Work Safety Analysis	4	Applied to chemical industry (Suokas 1982, Suokas & Rouhiainen), production (Wallberg et al), telecommunications and electricity transmission masts (Niemela et al 1999) Described in Health Technology Assessment (Woloshynowych et al in press

Appendix 4: Human Error Identification and Analysis Techniques

Technique	Definition	Examples of the application in healthcare
Barrier Analysis	Barrier analysis is used to examine the defences and controls that have been put in place to protect something or someone from harm, their effectiveness and suggestions for improvements (Hollnagel 2003)	As yet none, but has been discussed in the NPSA Root Cause Analysis toolkit http://www.npsa.nhs.uk/
Change analysis	Change analysis is a tool used in industry to analyse the effect of process changes – used for analysing the differences between normal practise and incidents.	Applied to the process of care that leads to patient incidents (Spath 2000). It is also used in the NPSA toolkit and training
CREAM Cognitive Reliability and Error Analysis Method	This involves constructing an event sequence in a specific situation. Next, for performance segments, it is necessary to describe actions and cognitive activities to determine the relevant cognitive functions and identify the likely error modes (Hollnagel 1998)	Not yet applied in healthcare
FMEA Failure Modes Effects Analysis	A FMEA is a systematic method of identifying and preventing product and process problems before they occur. This involves using a team of multidisciplinary experts to evaluate the process, what failures could occur and the severity and probability of the effects and what actions can reduce these effects.	Reducing risk in blood transfusion (Burgmeier 2002); Intravenous drug infusions (Apkon et al 2004) ; improving a drug distribution system (McNally et al 1997); drug prescription in wards (Saizy-Callaert et al 2001)
HAZOP Hazard and Operability Study	HAZOP involves a team of multidisciplinary experts evaluating processes using the application of guidewords – such as 'task not done', 'task done too late', 'task done too much' (Kletz 1999)	Medical imaging (Redmill et al 1998); cervical screening (Chudleigh 1994)
HEART Human Error Assessment & Reduction Technique	HEART is used to quantify error probability by applying weighting factors associated with error producing conditions to the relevant generic error probability associated with the types of task being examined (Williams 1986)	Widely used in industry but not yet applied in healthcare
Influence Diagrams	Influence Diagrams are a means of modelling and quantifying the effects of a number of contributory factors and human actions on outcome.	Medical decisions (Nease & Owens 1997, Bellazzi & Quaglini 1994); surgical problem solving (Magni et al 2000)
MORT Management Oversight Risk Trees	MORT involves the applications of a toolbox approach to analyse incidents in terms of the adequacy of the safety management measures already in place (Kirwan 1994). This involves the use of a fault-tree like structure to look at what happened, why it may have happened then examines these concepts in terms of systems and organisational failures and precursor events.	Not yet applied in healthcare

Technique	**Definition**	**Examples of the application in healthcare**
SHERPA Systematic Human Error Reduction and Prediction Approach	SHERPA is a comprehensive technique involving task analysis. SHERPA identifies error modes. (not done, partially done, too little) and 'psychological error mechanisms' – the thought processes that may fail or lead to errors, potential for recovery from error, the consequences of error and error reduction strategies (Embrey 1987)	Errors in endoscopic surgery (Joice et al 1998, Malik et al 2003)
THERP Technique for Human Error Rate Prediction	THERP is a total methodology for human reliability analysis – from task analysis, development of event trees to error quantification. Similar to HEART, for quantification, this involves the use of nominal human error probabilities adapted by the relative effects of Performance Shaping Factors to determine success and failure probabilities as well as looking at the effect of recovery effects (Swain & Guttman 1983 cited in Kirwan 1994)	Widely used in industry but not yet applied in healthcare

Appendix 5: Approaches to human error quantification

Technique	**Definition**	**Examples of the application in healthcare**
Absolute Probability Judgement	For this experts are simply asked their judgement on the likelihood of specific human error and the information is collated mathematically for inter-judge consistency	None reported in healthcare
Event Trees	An event tree is a tree-like diagram that splits according to escalation and recovery events as well as an operator's choices between responses at each stage. Usually the probability of given branches is calculated thus providing the expected probability of each outcome. In addition, the concept of Cognitive Event Trees have been developed to examine the effects of decisions.	Ambulance treatment of patients with suspected MI (Stoykova et al 2004)
Fault Trees	A fault tree is a tree diagram using AND/OR logic which is used to examine how an incident occurred or could occur due to contributing factors and events	Potential exposure risk for radiotherapy staff (Tofani et al 1999); medication error (Dhillon 2003); medical device failure (Marx & Slonim 2001)
Paired Comparisons	This is similar to the absolute probability judgement except the experts are provided with task descriptions with known error probabilities to use as a baseline	None used in healthcare

Appendix 6: Task Analysis of a patient processed in majors

(Plan: do in order as written)

Task No.	**Task**	**Sub-task No.**	**Sub-task**	**Sub-sub-task No.**	**Sub-sub-task**
1	Nurse sees patient				
2	Nurse sees CASCARD				
3	Nurse makes initial assessment				
4	Nurse gives brief summary of information to doctor (if in this order)				
5	Doctor examines patient	5.1	Doctor reads CASCARD		
	(plan 5: – do in any order)	5.2	Doctor asks questions		
		5.3	Doctor performs examination		
6	Doctor writes prescription	6.1	Chooses drug		
	(plan 6 – do in order as written)	6.2	Checks for contra-indications (and allergies)		
		6.3	Choose dose		
		6.4	Choose route		
		6.5	Check in BNF if uncertain		
		6.6	Write up prescription on form		
7	Doctor gives prescription to nurse (may ask additional questions at this stage)				
8	Nurse takes prescription				
9	Nurse seeks drug cupboard keys				
10	Nurse opens drugs room				

Task No.	**Task**	**Sub-task No.**	**Sub-task**	**Sub-sub-task No.**	**Sub-sub-task**
11	Nurse prepares and dispenses* drugs	11.1	Nurse looks at prescription		
	(plan 11: do in order as written)	11.2	Nurse considers prescription in light of patient condition		
		11.3	Nurse opens relevant drugs cupboard		
		11.4	Nurse collects oral NCD drugs	11.4.1	Take out packet of drugs as defined on prescription
			(plan 11.4: do in order as written)	11.4.2	Check outer packet – drug, dose, expiry date against prescription
				11.4.3	Check inner blister pack – dose, drug, expiry date against prescription
				11.4.4	Dispense drugs into cup
		11.5	Nurse collects other drugs		
		11.6	Nurse locks cupboard (keeps keys until opportunity to return them)		
12	Nurse rechecks queries with doctor (if required – requires return to 9)				
13	Nurse returns to patient with drugs (collecting water on the way)				
14	Nurse checks ID of patient – name, date of birth and allergies				

Task No.	**Task**	**Sub-task No.**	**Sub-task**	**Sub-sub-task No.**	**Sub-sub-task**
15	Nurse administers oral drugs	15.1	Nurse explains what the drug is for (obtaining consent)		
	(Plan 15: do in order as written)	15.2	Nurse checks patient status at current time to check drug / dose and route are still appropriate		
		15.3	Nurse gives drugs and water to patient		
		15.4	Nurse witnesses patient taking drug		
		15.5	Nurse signs drug chart entering correct time in correct format		
16	Nurse administers other drugs				
17	Nurse returns drugs keys				
18	Nurse monitors patient for any change				
19	Doctor makes decision about patient destination				

* ‘dispenses’ in this context refers to the process of preparing the medication and is distinct from the role of the pharmacist

Appendix 7: List of Errors identified

Errors in prescription	**Errors in nurse dispensing**	**Errors in administration**
Prescription process not carried out	Dispensing process not carried out	Administration process not carried out
Prescription process carried out when not required	Prescription chart not given to dispensing person	Administration process carried out when not required / carried out when already been done.
Prescription process carried out when already been done.	Prescription not checked by dispensing person	Administration process carried out too early (i.e. before prescription)
Prescription process carried out too early (i.e. before examining patient / patient’s notes)	Drug not found	Administration process carried out too late (for patient’s condition)
Prescription process carried out too late (i.e. after drugs have been given)	Dispensing process carried out when not required / when already done	Administration completed correctly but not communicated orally or written on drugs chart.
Correct prescription decision made but not communicated (either orally or written)	Dispensing process carried out too early (no prescription given / examination not completed)	Administration completed correctly but written on wrong chart
Correct prescription decision made and communicated orally but not written	Dispensing process carried out too late (for patient’s condition)	Administration not carried out but recorded as completed on drugs chart (either due to staff factors or patient not taking drug when staff believed they had)
Correct prescription decision made and communicated orally but written on wrong chart	Dispensing wrong drug for patient (consistent with prescription)	Administration process not communicated to patient / communicated inadequately
Correct prescription decision made but not communicated orally and written on wrong chart	Dispensing incorrectly prescribed drug	Drug administered to wrong patient
Wrong drug(s) prescribed (written) (wrong due to being for different problem AND/OR wrong due to patient-specific factors)	Dispensing wrong dose of drug	Drug administered to wrong patient but recorded on correct patient’s chart
Correct drug(s) communicated orally – wrong drug written up	Dispensing too many tablets (of one type)	Incorrectly prescribed drug(s) administered
Wrong dose prescribed (written) – too much / too little / no dose written	Dispensing too many drugs (of different types)	Wrong drug(s) administered (contrary to prescription)

Errors in prescription	**Errors in nurse dispensing**	**Errors in administration**
Correct dose communicated orally – wrong dose written up	Dispensing drugs for more than one patient at a time	Succession of drugs administered in wrong order (if relevant)
Wrong rate prescribed (written)	Checks not carried out	Correct drug(s) administered orally – wrong drug and prescribed and signed for (unusual but possible!)
Correct rate communicated orally – wrong rate/no rate written up	Drugs dispensed into wrong ‘vessel’ (soluble paracetamol in syringe)	Wrong dose administered – too much / too little / no dose given
Wrong route prescribed (written)	Dispensing process carried out poorly (eg. Poor hygiene)	Correct dose administered – wrong dose signed up (unusual but possible!)
Correct route communicated orally – wrong route written up / no route written	Dispensing process not recorded (where required)	Wrong rate administered
Wrong time written on prescription	Dispensing process recorded wrongly (where required)	Drug administered though wrong route
Drug written on prescription of wrong patient	Dispensing process recorded when not required (eg. CD signed up when not taken)	Wrong time written on drugs chart
Drug prescribed for wrong patient but communicated orally for right patient		Chart not checked (where relevant)
Drug prescribed for right patient but communicated orally for wrong patient		Chart not found (where relevant)
Prescription poorly written		Patient not located
Prescription not re-checked (only where required)		Drug poorly administered (other harm done)
		Drugs administered to more than one patient at a time
		Patient not checked / monitored following administration