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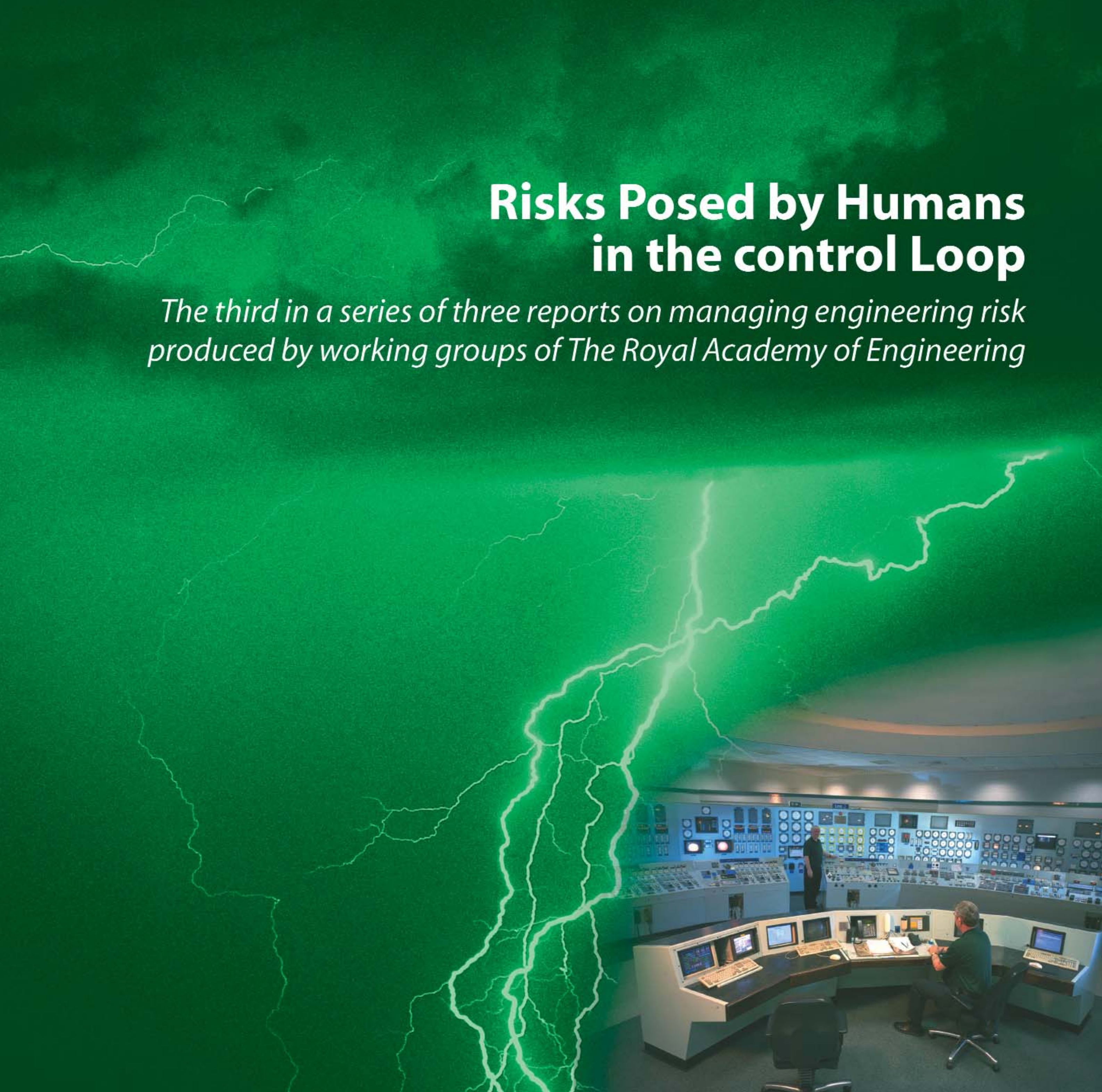
Risks Posed by Humans in the control Loop

The third in a series of three reports on managing engineering risk produced by working groups of The Royal Academy of Engineering



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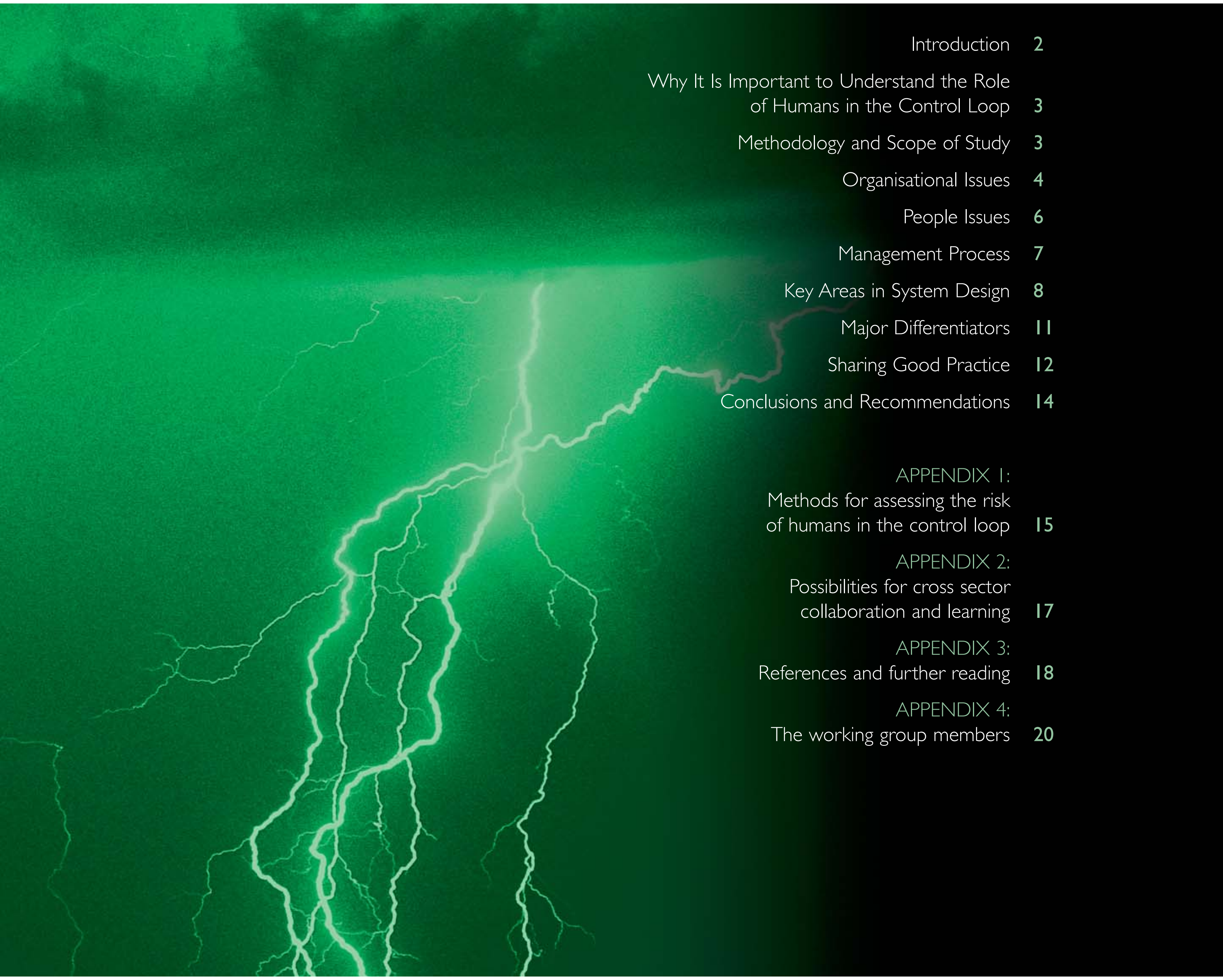
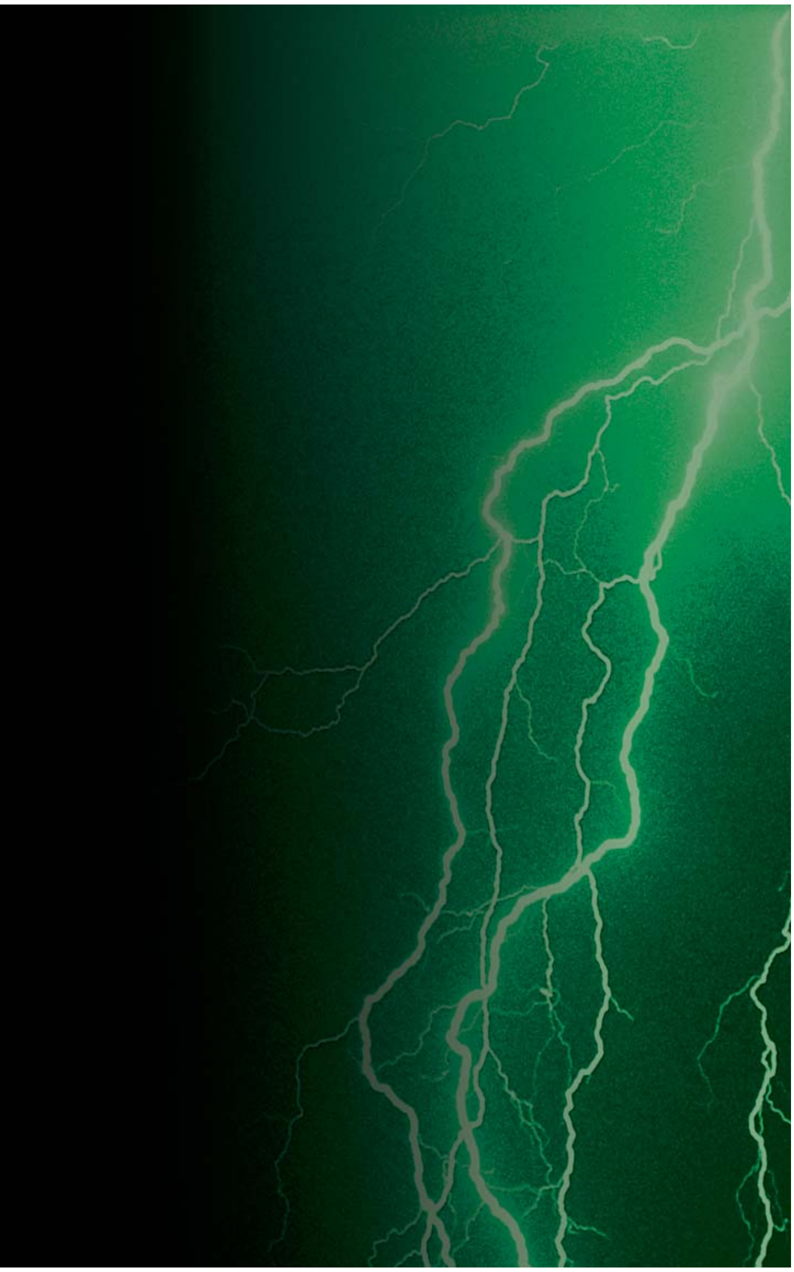


Introduction

The Royal Academy of Engineering convened a Working Group to research and review current thinking and best practice in respect of the risks posed by human operatives controlling complex engineering systems. This report summarises their conclusions.



The Group set itself the objective of understanding the impact of human involvement in the 'control loop' and to identify good practices that should be shared across different industrial and service sectors. Understanding the benefits of sharing good practice is not difficult to see. But there are attitudes and behavioural issues that prevent open acceptance and implementation across different sectors that need to be addressed.

The Working Group considered a representative cross section of industries and service sectors. It sought to identify their different approaches to the effects that technology change has had on people, and the potential impact that associated Human Factors can have on risk. The Group also looked at examples of best practice in assessing the potential effects of such risk and how best to manage the people/technology interface to reduce potential problems. Further work has been proposed for consideration. During its deliberations the Working Group has always been mindful not to produce a set of human factors lessons for the engineer, but to provide a more strategic treatment of the issues.

Why is it important to understand the role of humans in the control loop?

The Working Group has assembled research that establishes that humans are much less reliable at performing routine repetitive tasks than machines, and that human error is a frequent cause of malfunction in complex systems. People are often given tasks in the control loop for which they are not well suited, for example, watch keeping duties in control rooms, spotting danger signals on the railways and the roles of pilots in modern high-performance aircraft - all potentially boring and monotonous tasks. And yet after an extended period of low activity, they can then be faced, without warning, with very demanding tasks in emergency or control failure situations.

It is well understood what people are good at and what machines are good at, and the underlying principles (both physiological and psychological) have not changed since Paul Fitts first described them in the 1950s. As a consequence the need for designing systems around people rather than fitting the operator to the task is seen as one of the important facets of the challenge facing systems designers. Without this, the human controller, or operator is asked to perform as an automaton rather than a person and the consequential risks can have serious consequences for safety and optimum system performance and, thus, the reputation and profitability of the responsible enterprise.

It is essential therefore to take a systematic approach to understanding risk at the interface of technology with human beings. This report suggests how best to go about developing this understanding and concludes that much can be learnt by sharing and comparing practice across disciplines and industrial sectors.

The Working Group's analysis identified four key themes that emerged when considering the differences between sectors when assessing the contribution made by the human in the control loop to risk. The themes are:

- System design and operator control as sources of error
- Reporting feedback loops and organisational learning
- Licensing and training personnel and checks of competency
- Varying levels of automation within the industry

These themes recur throughout the report and the Working Group considers it essential that they be addressed by those responsible for the design and operation of complex systems that utilise human controllers in combination with automatic control.

Methodology and Scope of Study

The Working Group, which included human factors specialists, analysed the different approaches used in six safety critical sectors to organisation, people management, safety and reliability related processes. A number of standard short questions were developed and the analysis was based on answers provided by members of the Working Group. The six sectors considered were:

- Aviation
- Chemical/Petrochemical production
- Marine
- Medicine
- Nuclear Power
- Railways

It was not considered appropriate to report the specific findings for the individual industries. But a summary of the spectrum of good and poor practices is provided below. A set of common themes was identified and is considered a basis for the potential transfer of technology across industries. Some case studies are also discussed.

Organisational Issues

A Corporate Vision is the explicit statement by senior management of the ethos of the company. It is important that every level of the organisation understands the overarching reasons for the vision, and that the organisational structure, management processes, technology and human resources create a supportive framework to 'live the vision.' It is crucial that the vision and values be communicated and the effectiveness of the communication is verified.

Potential Barriers to Communicating Corporate Vision and Values

- A geographically dispersed workforce
- A mobile workforce operating away from 'base'
- An organisation hierarchy with many layers
- Shift working
- Outsourcing to contractors of critical operations

But communication of itself is not enough. It will simply confuse in situations where the vision is not embedded in processes, and where there are conflicts between business drivers and the operators' ability to achieve the goals set by their managers.

There is also a need for a clear and explicit risk management strategy. The need for such a strategy at corporate level is also made in another report in this series on Risk Management Methodology. Pilots in combat military aircraft have quite different criteria to work to than those in civil aviation. A control panel operator of a petrochemical plant processing hazardous material located near an urban area will need a different strategy from his/her counterpart in a water treatment plant in a remote location.

The risk management strategy needs to define the overall philosophy of the organisation in handling risk. While this may seem obvious it is by no means easy to implement and developing a strategy takes both effort and skill. Management has to be prepared to invest this effort and to involve the work-face staff in the exercise. Failure to do this and then to communicate an imposed top-down strategy will lead to frustration and confusion in the control loop. A bus driver needs to know whether strict adherence to speed limits is more or less important than punctuality. An air traffic controller needs to know how to operate when the computer aids are not working reliably. Both need strategies expressed in their terms.

The way that organisations seek and deal with information about their performance was thought crucial to understanding how human factors issues are managed within organisations. A range of behaviours was identified and the Working Group felt that each of these could be found in practice amongst the safety critical industries under consideration.

Worst case	Middle case	Best case
Don't want to know	May not find out	Actively seek it
Messengers (whistle blowers) are 'shot'	Messengers are listened to if they arrive	Messengers are trained and rewarded
Responsibility is shirked	Responsibility is compartmentalised	Responsibility is shared
Failure is punished or concealed	Failures lead to local repairs	Failures lead to far-reaching reforms
New ideas are actively discouraged	New ideas often present problems	New ideas are encouraged & welcomed

Some organisations had difficulty managing information that indicated adverse performance or behaviour whilst other organisations actively sought it and the "messengers" were rewarded for their actions.

The Working Group considered the collection of data about incidents and accidents a critical differentiator between industries. Good practice was reflected in organisations that developed reporting schemes to collect information about near misses in order to identify system improvements that could prevent actual accidents from occurring. However, some industries have not established comprehensive reporting schemes, have no confidential reporting mechanisms and have not recognised the value in trying to define near misses. The Working Group recognised that there are large differences within sectors and that some industries are making appreciable attempts to improve. An example of this is the reporting scheme of the National Patient Safety Agency. This collates and analyses reports of adverse incidents in medical practice.

A Tragic Case History and Its Learning Points

A child was due to receive chemotherapy. No beds available in oncology ward, admitted to outlier ward. Patient should have fasted, but was allowed food and drink.

- Lack of beds for specialised treatments put patient into an environment lacking appropriate expertise - **Organisation**
- Fasting error - **Communication**

Patient's notes lost.

- **Organisation and training**

Patient due to receive two separate drugs - one intravenously on the ward by a specialist nurse, and one spinally under general anaesthetic in operating theatre by oncology specialist registrar. Both intravenous and intra-spinal drugs transported to the ward by a housekeeper

- Lack of **communication** between oncology department and outlier ward.
- Lack of policy and resources to cope with requirements of outlier wards for specialist staff.
- **Organisation**

Housekeeper tells ward staff that both drugs should go to theatre with the patient.

- Non-compliance with or ignorance of hospital policy of keeping these drugs separated. Poor delivery practice – drugs delivered by inexperienced staff.
- **Management Process and Training**

Abbreviation of administration route of drugs to 'IV' and 'IS' instead of writing out fully in capital letters.

- **Communication and Training**

Fasting error discovered - procedure delayed to afternoon list, originally planned specialist now unavailable. No formal face to face hand-over between the morning specialist and the afternoon specialist on the ward.

- Inadequate hand-over procedure.
- **Communication, Management Process and Training**

Patient eventually in anaesthetic room. Senior registrar called to administer the drug, but he could not leave his current task. He instructs anaesthetist to carry out procedure but is unaware that both drugs have been delivered to the theatre. The anaesthetist administers the intravenous drug intra-spinally , and the spinal drug intravenously.

- Inadequate protocols for the administration of high toxicity drugs.
- Conflict between ward and theatre duties.
- Inappropriate task delegation.
- Management Process.
- Communication and training.

The patient dies 5 days later

People issues

The study concluded that humans were still clearly operationally important and a regular part of the control loop in all sectors except in the simplest 100% automated systems. However, one industry with large quantities of investment in automation has reduced the role of the operator to a watch keeper/supervisory role. This has led inevitably to a very difficult situation and series of tasks for the operators when the automatic systems fail and the system reverts to manual mode. However, experience indicates that this investment has resulted in a more efficient and safer industry.

An important theme is the different causes of human error introduced into the system. In largely manual systems, which require virtually continual human intervention, the source of error is generally the operators. But they obtain immediate response and feedback from failures or deviations whether caused by technical or operator problems. This enables them to build up experience, to understand system behaviour and to handle all but the most serious eventualities. In highly automated systems failure is much reduced. However, in such systems design engineers can induce human error if they have not identified all the operational eventualities and provided a suitable control process or system for those circumstances. These are generally referred to as latent failures that can remain in a system in benign fashion and not be identified until the specific operational eventuality is encountered leading to accident or incident. In this situation the operator is largely unprepared and unable to cope due to the complexity of the system. This theme of a continuum of low levels to high levels of automation leading to a continuum of different error causes is an important issue for the engineering community to be aware of and to address.

The Working Group decided that a review of the total skill base required for the six different sectors was too large a task. It was reduced to a manageable level by considering only the 'frontline' operators (e.g. surgeons, control room personnel and bridge personnel of sea-going vessels). In general the Working Group felt that in each sector such personnel were suitably competent for the tasks they were required to undertake. However, it was recognised that some industries were in the midst of substantial changes in the required job competencies caused by technology or organisational development. Good practice was identified within some sectors where these large changes have been recognised and large scale retraining schemes implemented. An excellent example of good practice was the initial take up of Crew Resource Management (CRM) training in a number of industries, which have recognised that it may not just be technical skills which are required for successful outcomes, but also non-technical skills. These include communication skills, workload management, and team working.

Large differences were identified between sectors with regard to simulator usage. Simulator usage was identified as the mainstay of the training, development, and competency checking for two of the industries. In these cases full simulator competency is required before the operator is allowed to practice with real equipment. In at least two of the sectors there appeared to be very little take up of simulator technology. Part of the difference could be attributed to the difficulties in developing the simulation. But the group felt that even basic simulation technologies with appropriate 'cognitive fidelity' (thoughtful representation of the problem) could be utilised successfully to develop and test the competency and skills of humans in the control loop activities.

The study revealed some minor differences between initial competency checks but substantial differences regarding the requirements to recheck to remain qualified. All industries have good induction training in place and associated qualifications. However, rechecking of qualifications or competency was quite different between sectors. Some had rigorous medical and competency checks every 6 months. Failure at this check would lead to barring from all operations. Other industries used a gated entry system, like a driving licence, which once attained was not tested again until retirement. The group felt that in industries where technology and skill bases change rapidly, it is essential that competency should be re-tested to ensure that individuals remain up to date.

Management Process

The cross industry survey revealed some quite substantial differences in the use of standard operating procedures. One industry had a requirement for standardisation of procedures by legislation with minor differences between companies. Most other sectors had robust standard operating procedures but these were not controlled or enforced by any regulatory authority.

However, the most significant difference was the level of self-assurance. Were operators expected to check for their own errors through self assurance, or was a cross-check undertaken by another person in order to fully identify and deal with human operational errors? Two of the industries had no requirement to cross check, and this was felt to be a likely source of risk. The Working Group believes that the ability of cross-checking to mitigate likely sources of human error is determined not just by the requirement for a check, but by the quality of the check. A poor cross-check by someone who was unable to challenge a superior's decision was not going to catch errors. However, safety cases in some industries claim an order of magnitude improvement in reliability if a task is cross-checked.

The survey revealed large differences in the use and the extent of checklists. Checklists are a simple job aid that aims to provide a prompt that reduces the likelihood that standard operating procedures are not followed, or steps omitted. They seem particularly useful at catching 'slip' type errors where operators had the intention to perform the activity but were distracted by another task or simply forgot they had not performed the task. Two industries surveyed had operations based upon checklists but others had very little mandated use of checklists. A member of the Working Group had observed the use of checklists by individuals in a particular high-risk environment, and this particular part of the industry had a measurably better safety record than other parts of the same industry.

Key Areas in System Design

In assessing degrees of risk, everyone would like the calculation to be rational and made in a straightforward and clear way. Unfortunately, it is often the case that not everyone agrees what these terms mean when applied to a particular calculation.

Human Factors is a discipline that takes a holistic, human-centred, systems view of the design of a task, the equipment needed to carry out that task, the interface between the person and the equipment, and the environment within which it is executed. 'Can this individual, do this task, with this equipment in this environment?' The discipline has built up a body of knowledge and understanding of the behaviours of people in complex systems and has developed tools and techniques for assessing human performance. This is important both for normal operating conditions and also under more extreme conditions where human adaptability is stretched to cope with conditions that may or may not have been considered by the system or process designer, and where the outcomes are less certain. However, risk is not only present in extreme conditions since every incident involves not only an active failure but also latent conditions that contribute to that occurrence.

The role of operators in high-risk industries is clearly an important aspect of overall system design. There is a general consensus that operators' tasks, within control rooms (petrochemical and nuclear), train cabins and civil cockpits, have been largely automated, leaving operators for the majority of their time as system supervisors and not system controllers. This trend is continuing for air, rail and marine traffic control. It is only when an event beyond the design limits of the automatics occurs, that the operator has to take control and guide the system back to its normal parameters. There are also job designs at the other end of the spectrum which are equally difficult and stressful for the operators, where they are required to repeat extremely mundane tasks without error (e.g. pathology laboratory technicians). The effect of such job designs or 'allocation of function' between operator and machine has a number of implications for system risk particularly with respect to managing human error.

This key contribution of human error to incidents is generally understood. The importance of risk assessment is also well understood across industries. However, there often appears to be a gap in terms of linking these to produce risk assessments that focus on the human contribution to risk. Industries clearly do control risks through a variety of methods (e.g. acting on incident investigations, training, equipment design, etc.) but this does not appear to be based on a structured proactive assessment of the human contribution to risk. The need for such assessments and their benefits should be more actively promoted.

Historically, there has been a strategy in many sectors of aiming to reduce or eliminate human error by automating the process or task. This may be successful in curing one symptom or cause of error, but in doing so may introduce different kinds of errors in different parts of the system that may not be immediately apparent. There is a continuum of automation from complete manual control and full decision making on the part of the operator to completely autonomous control with virtually no role for the operator, no decision making or even monitoring. Intervention can be at the level of information provision, advice and/or guidance, control assistance, control intervention or complete automation. The key question is where it is most appropriate to pitch the automation level, and can the operator easily switch from one level to another and still be able to understand and control the system. Good examples of such automation continua are given in Billings (1997).

Control tasks are generally the first to be automated, with decision-making tasks implemented much later.

Levels of operator involvement in terms of control, decision making and monitoring are inversely proportional to the increasing automation level. These types of continua help to identify the man/machine roles and to predict how the system might work under both normal and abnormal conditions.

Management needs to be alert to potential change or even perceived change in either control responsibility or legal responsibility and to assess whether or not this constitutes a problem. When there is a critical situation in air traffic control for example there is not a 'blame free' culture. Responsibilities are accurately defined and errors are attributed. With the changes in negotiation of flight paths and the creation of more human-removed communications (e.g. sending instructions to pilots at a pre-defined time by a button press), then the clarity of responsibility and the attribution of error between system, pilot and controller may become more difficult.

Where different levels of automation are involved, operators must be able to switch over from one level to another and be aware of the control limitations and capabilities at each level. Moreover they need to be aware of the automation mode they are in so that they correctly understand the system responses at that level.

In any system the operator needs to be able to locate errors and to recover from errors in a timely and efficient manner before the situation becomes critical. When new technology is introduced, new errors may be generated from unpredictable sources. Consideration needs to be given to error tracking and error management so that both errors and the results of errors can be minimised. One major aspect of this is the system response to error, and how it might aid the operator to find a solution. The system may offer options and also tools to predict the outcome of various options.

Humans in the control loop need to be aware of potential errors that the system may generate, particularly relating to the reliability of data and the assumptions that the system may make about what is 'correct'.

Warnings are another aspect of the way that the system deals with errors. One error may trigger several other errors and the system may issue sound or visual warnings for each error, but not indicate the causative error or the order in which the malfunction should be corrected. Some systems rigidly require historically earlier errors to be corrected before they allow later errors to be re-set, and this is difficult if there is no indication of the order in which the errors or exceptions occurred. The time taken to correct errors must also be considered. There have been examples from warning systems in aircraft cockpits where there have been a significant number of errors signalled but fortunately, the crew had the help of a back up crew. This made available four experienced pilots who were able to cope with and correct all the errors to make a safe landing. Some attempts have been made to order error handling and the 'quiet dark cockpit' concept is one of these. Essentially all is well if there are no warning sounds or lights. Intelligent warning systems are being developed which give warnings of errors, help in the treatment of multiple warnings e.g. which warning to deal with first, and how to minimise the impact of the error.

The method of error handling may depend on the level of automation and the role of the operator. One danger implied here is over reliance on the technology/system, to the exclusion of other less sophisticated but more rugged systems that may need to be used when there is a failure. More insidious is system error without the operator realising it, possibly caused by unreliable data. The degree of error is also important. Currently Air Traffic Controllers for example, know the error in the data that they receive and are able to take it into account when issuing instructions. System integration is also an issue here in the sense that if the integration is poorly done, errors may occur because of the integration itself.

The organisational structure has a role to play in supporting the workforce in living the vision and values of the organisation. Although the operator may be closest to the impact of an incident or accident, the sources of the error may lie in a tangled network of processes back through the organisation, where failures have occurred at different levels promulgated by different people. Errors and failures at other parts of the organisation may have gone unnoticed on previous occasions and not caused a significant event because the failing events were not additive. This is termed organisational error (Reason, 1997). Conflicting signals may be sent if the meaning and reasoning behind procedures, and requirements laid down by management, are not fully understood by the people who have to carry them out. The operator may also be pressured to meet business objectives that contradict safety procedures, and may be subject to performance review based on the business objectives rather than on adherence to the standard operating procedures.

There are basic human factors guidelines for the design of displays, control centres, information management systems, management of change and so on. ISO 11064 for example deals with human factors in control rooms. It includes principles for the design of control centres, control suite arrangements, control room layout, workstation layout and dimensions, displays and controls, environmental requirements, evaluation principles and requirements for specific applications. There may also be a need for guidelines for the introduction of new working practices, and certainly new procedures for dealing with both normal and abnormal situations.

New systems need to be certified for their complete operating envelope. There are various issues that need to be addressed. It is clear that the normal operating envelope needs to be tested, but what other non-normal conditions should be tested, and how many of these should be included in continuous training schedules for operators? Who should certify operator performance?

New sub-systems cannot be tested in isolation. A new sub-system may make an existing acceptable system unacceptable by fixing or increasing capability on one area whilst decreasing capability or adding confusion in another. A total systems approach is required. Similarly adding 'commercial' off the shelf (COTS) items to existing systems requires them to be tested as a whole. The COTS item may be fine on its own but may create new problems installed in parallel with the rest of the systems.

Current thinking suggests that a whole range of testing techniques is required rather than a pass/fail for a specific set of conditions. This includes certifying the process for development as well as certifying the outcomes. Expert views are valuable assessment techniques as well as objective measures when possible.

High job turnover may be a result of operator resistance to change, where highly skilled personnel are disgruntled and feel that their jobs have been changed, requiring either reduced skills or requiring additional skills, or are even outsourced meaning that they work for a different organisation.
There is a need to prepare the workforce for changes in skill requirements in order to maintain competency and the skill base needed for continuation of the industry.

New systems may be vulnerable to misuse or not used as the manufacturer or designer intended. Examples of this might be the use of home based or ground based systems that are then installed in the car or cockpit, like access to the Internet in the car, or hand held GPS systems in the aircraft cockpit. Feedback mechanisms then become even more important in order to gain a picture of the true success of the changes and to gain insights into the emergent or adaptive behaviours caused by the change.

Major Differentiators

The major differences between the sectors were seen to lie in the four areas identified earlier. The first was the potential for error inherent in the system design and the operator's control role. The second was the organisation ethos in respect of incident/accident reporting, feedback and learning. The third concerned the licensing of personnel and regular checks of competency. The final theme is the degree of automation.

As discussed above, there is a continuum of control between fully manual and fully automated operation of a process and this is evident in a comparison of the type of human errors that lead to catastrophic system failures. In those cases where there has been insufficient automation operators may be asked to work at or beyond the bounds of human limits. For example, the statistics show that it is unlikely that a train driver will pass a signal at danger in their driving career. Given the number of danger lights actually experienced this suggests almost machine like reliability. At the other end of the continuum is the highly automated system in which people act as monitor and are not required to act until something fails. These systems are typified by advanced aircraft systems that may not require any substantive alteration in the aircraft's configuration for 8 or more hours.

The Ladbroke Grove accident occurred on the 5th October 1999: a Thames Trains Turbo collided nearly head-on with an express train resulting in 31 fatalities and injuries to over 400 other persons. In the events leading up to the collision, a recently qualified driver failed to stop at a red signal. It was the first time he had driven the particular route on his own. Signal SN109 was recognised as being difficult to locate, though it is not known for certain what caused the driver to miss the signal and fail to stop.

An alert signalman detected the error soon after it occurred (despite a poorly designed alarm system). However, he expected the driver to detect the error, stop and contact the signal box on his radio since this is what had always happened previously. The signaller waited, the call never came and the train continued towards a certain collision. The signaller started to take action, but it was too late. It transpired that the relevant procedures were ambiguous on the course of action to be taken, the signalling system provided no quick method of initiating a recovery procedure and the signalman had never been given the chance to practise the steps required.

The incidence of accidents such as Ladbroke Grove will be weighted by a series of 'performance shaping factors'. It could be argued that this is an example where the rail system would benefit from greater levels of automation. As a minimum, an interlock is required which prevents a single error (driver failure to act on a red light) from leading to a catastrophic accident. Or at least a process that allows the system (signalman initiates a recovery procedure by separating the trains or warning them of the impending collision) to recover from a single person's error.

The Ladbroke Grove accident could also be seen as an example of insufficient corporate learning. As the case study quotes, it was well known that the lights at this junction were difficult to locate. If data regarding signal sighting were collected and acted upon, this particular accident may have been avoided.

The railway industry has made big inroads regarding the management of data with the creation of their own confidential incident reporting system (CIRAS). This is similar to a system started in the CAA called CHIRP (Confidential Human Factors Reporting Procedure). This system allows individuals who have identified a potential problem in their working environment to register the incident without fear of retribution for not conforming to the standard operating procedures. This is a good example of the migration of applicable risk management techniques between industries.

The issue of licensing personnel in complex systems is an important theme running through the comparison of different safety critical industries. If an industry continues to develop its systems and introduce new techniques and technology it is also necessary to ensure that the personnel are familiar with the system that they are operating. Continuing training of already certified personnel was identified as a key theme in the Bristol baby heart operation enquiry. If the risk of the human operator in the control loop is to be addressed it should be managed with regard to the competency of not just the new operator but also the experienced operator who needs to keep up to date with the evolving working environment.

Sharing Good Practice

The principles and basic processes for assessing human performance are highly transferable between industries. The processes of supervision and management (accident investigation, quality systems, etc.) are required in most industries and there should be no barrier to transferability. It is generally believed from the Working Group's analysis that migration of appropriate methods between industries would enhance safety by enabling industries to adopt the most effective risk management strategies. The effectiveness of this activity relies upon the assumption that most effective techniques for solving problems are not necessarily new ideas but the adoption of existing ideas in a new domain. A good example of this is the Dyson™ vacuum cleaner where paint shop air filtering technology was transferred to a domestic cleaning appliance.

The Working Group could find no specialist research into the nature and process of transferring human factors technology between industries. However, the work concerning the general transfer of practices between industries seems applicable.

For practices to transfer between industries three gates need to be passed. The new practice needs to be:

- Communicated to the receiving organisation
- Comprehended by receiving organisation
- Implemented by the receiving organisation

Failure of transfer can occur at any one of these gates. The barriers and promoters to the transfer of human factors technology are well documented by Souder and Pamanabhan (1989) who undertook a study of transfer of this technology in twelve different industrial organisations. The most significant barriers were:

- Inadequate staffing by the receiving organisation
- The technology was considered too fragile
- The technology was considered to be too complex
- The receiving organisation management feared disruption of the plan schedules, and
- The receiving organisation management was preoccupied with other problems.

The most significant promoting factors were:

- Counterpart top-level champions
- Receiving organisation involvement in the design work
- Vendor's or delivery organisation's early involvement in the project
- In-plant organisation demonstration by a joint team from receiving and delivering organisation
- The receiving organisation dedicated an experienced (well-respected) engineer.

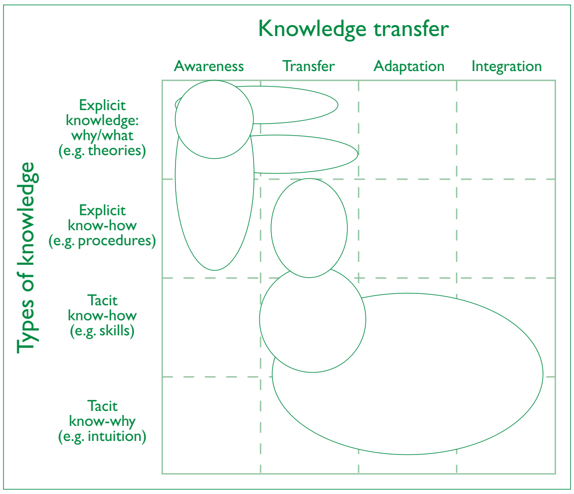
There are a number of approaches that could be adopted to assist the transfer of human factors techniques between industries. These ideas are a summary of the work of Wolff (1985) who has studied the transfer of technology between industries and between research organisations and Cavanagh (2001) who has developed techniques for learning from experience.

The principle basis of good transfer relies on establishing good communications, but also the provision of experiences, environments and frameworks within which transfer can take place. Potential requirements and mechanisms include:

- High-level management commitment to transfer technology
- Transferring people from giving and receiving organisations
- Informal sharing of experience with a broad range of disciplines.
- Establish credibility
- Conduct technical reviews
- Understand the differences and similarities between organisations

- Conduct 'tours of the unfamiliar' – challenge individuals to find solutions outside their own domain
- Use a centre of expertise for short periods of time (e.g. consultancies who have experience in other industries)
- Review and learn – review each project at completion and evaluate successes and failures
- Temporarily transfer employees between organisations
- Mentoring and coaching from experienced personnel to harmonise good practice across the whole of the industry.

The process of organisational transfer is summarised in the figure below. This figure describes the knowledge transfer process from awareness to integration according to the types of knowledge.



CIRAS

The rail industry has a new large scale reporting system to address railway safety. It is called CIRAS - or Confidential Incident Reporting and Analysis System. The CIRAS system has been established from looking at the working of the CHIRP (Confidential Human Factors Incidents Reporting Procedure) which has been established for a number of years in the civil aviation sector. This system has significant human factor inputs and provides the opportunity for staff from the railway industry (e.g. drivers, signallers and maintenance personnel) to confidentially submit reports on issues or events related to safety. Where necessary, relevant actions are taken to investigate or remedy the reported problems and a quarterly journal describes the issues raised and any actions taken. 400 problems were tackled on the railways in a year on the basis of CIRAS reports. Also, it has been reported that the detailed description of real problems embodied in CIRAS reports is having a definite influence on discussions at the national level. Examples of the topics reported and responded to by the industry are working practices, shiftwork, fatigue, training and the human-machine interface (e.g. driver interface of signs, signals and lights).

Conclusions

There are wide differences between different industrial sectors and professions in their approach to integrating the 'human operative' into the control loop. While the differences are explicable in terms of history and tradition they do raise significant concerns, given many of the similarities in terms of the problems being addressed and the control requirements of the various systems.

The working group found little evidence of extensive concerted exchange of experience and best practice across the various sectors and believe that this represents a major lost opportunity to improve performance, reliability and safety.

Humans are generally the most vulnerable elements in the control loop. Thus the trend to increased automation is to be welcomed and resistance to automation has to be vigorously questioned.

As well as automation *per se* control actions are becoming increasingly complex. The controversy that surrounded the introduction of 'fly by wire' into civil aviation illustrates the potential problems. The feedback received by the operative becomes fundamentally different and is often counter intuitive.

In general terms, increasing automation can devalue the status of the human controller and make him/her ever more remote from the detailed knowledge and 'feel' for the system that is essential if deviations from 'normal' are to be recognised and interventions are to be effective. It is incumbent on systems designers and managers to understand this problem and address it explicitly. We saw this process evolving most clearly in the changing role of the pilot in large civil airliners.

At the other end of the spectrum we identified that by and large the medical world still sees the operating theatre as a scene where each intervention is different and has to be modulated to match the individual and unique characteristic of the patient and the style of the surgeon. Yet this is a field where technology is moving fast and interventions are becoming ever more complex and place increasing stress on the surgeon and his/her supporting team. The group can see enormous potential for learning from other sectors' experience.

The group examined a range of systems which they believe provide some general lessons. These can be summarised in three different categories. Firstly, at the strategic and organisation level there is a need for clarity of aims and objectives to be translated into terms relevant to the controller at the 'sharp end'. While this sounds like motherhood we see countless examples where organisation complexity dilutes the aims and objectives to the extent that control is lost. The trend over recent years to more and more outsourcing and dependence on contractors has inevitably increased this risk.

Secondly at the management level there has got to be an honest and rigorous examination of the design of the control operative's job. With technology change and increasing automation every sector is seeing jobs that used to have a significant degree of 'art' and feel, being changed into more routine watch keeping activities ensuring that the machines are performing normally. More often than not this puts more pressure and stress into the job and this needs to be recognised and addressed. There is a particular message for engineers who need to put as much resource into determining what the operatives will do and how they will do it as they put into designing the automated control systems.

At the ‘workface’, be it a cockpit, a nuclear power station control room or an operating theatre, systems have to be provided that make the operatives’ repetitive and routine tasks meaningful and robust. In very general terms a well-designed system would be one in which all of the routine would be automated and the operative would only do the tasks requiring creativity, intuition and experience. The reality however is still a long way from automating many systems and human operatives are still required to do routine systematic checks. In such circumstances, engineers and system managers must pay full attention to the design of the operatives’ role and function. There is a lot of good practice, for instance the use of “checklists” to support operatives in some situations, to be shared across industries and sectors.

This work was only able to scratch the surface of a complex and widespread issue. It is proposed that a major seminar be organised to test the validity of our conclusions across a wider group of engineering professionals. If there is general agreement consideration should given to mechanisms for information and experience exchange across relevant industries and sectors.

There are several techniques that have been identified that would enable cross industry exchange including Learning from Experience techniques, workshops, forums, and multi-disciplinary and multi-industry collaborative projects that provide environments for exchange. The challenge is then to manage the knowledge and experience gained from these activities and to make this widely available. There is value to be gained from cross industry learning with regard to good practice of managing humans in the control loop.

Appendix 1:

Methods for Assessing the Risk of Humans in the Control Loop

With regard to the assessment of the risk of humans in the control loop, methods can be adopted for three key stages, which are:

- Understand the role of the human in the control loop through investigating current operations. This can be undertaken if the systems are already built and in operation. For systems at the design stage it may be necessary to use predictive methods, develop simulators or draw information from comparisons with equivalent systems.
- Decide whether the role of the human in the control loop is acceptable. For example, risk assessments should draw on the data from (1) to assess whether the risk associated with the role of the human in the control loop is as low as is reasonably practicable.
- Provide methods to support the role of the human in the control loop.

There is a requirement for steps 1-3 not to be a one-off process but part of a continuous monitoring and improvement process. All companies implement some methods at each of the three steps. The following table aims to present three examples of generally accepted methods, and for each generally accepted method, a less frequently adopted method which may be of value.

A useful reference for methods is:
Wilson, J.R. and Corlett, E.N. (1993) **Evaluation of Human Work: A Practical Ergonomics Perspective** Taylor and Francis, London.

Table 1: Methods for understanding the role of the human in the control loop

COMMON METHOD	OTHER METHOD
Accident investigation enables us to understand the contribution of those in the control loop to system failures.	**Near-miss reporting** systems allows us to understand the contribution of humans in the control loop before a system failure occurs. This promotes a pro-active rather than reactive approach to errors associated with the human in the control loop.
Supervisors' knowledge of how those they supervise carry out tasks in the control loop.	**Hierarchical task analysis** defines a structured approach to the collection of data on how a task is carried out in the control loop and subsequent representation of that task in diagrammatic form. It is a first step to understanding a task for the purposes of step (2). It also provides an important opportunity to explore the differences between how managers believe a task is carried out and how it is actually carried out in practice.
Audits aim to investigate how management systems are working in practice. Management system audits are required within Health and Safety Executive Regulations.	**Safety Culture Surveys.** It is recognised across industries that an effective culture is required if the risks associated with humans in the control loop are to be as low as is reasonably practicable. The UK Health and Safety Executive provides a culture survey which can be administered to find out staff perceptions of culture at all levels of an organisation.

Table 2: Methods for deciding if the role of the human in the control loop is acceptable

COMMON METHOD	OTHER METHOD
Accident statistics provide data which can be used to assess the contribution of the human in the control loop to accidents and, over time, to identify if the contribution of the human in the control loop is changing.	Human reliability assessment is a specialised set of risk assessment techniques which can be used to assess the risks associated with humans in the control loop. They are typically based on hierarchical task analysis (see table 1). They typically take each step of the task analysis and assess: 1. The possible types of error which can occur (e.g. omission of a task step or carrying it out too early). This stage is greatly enhanced through drawing on the experiences of error from the humans who are in the control loop. 2. Describe the contribution of the errors to risk. This may be qualitatively undertaken through expert judgement or more detailed modelling of the process may be undertaken to quantitatively define the impact of each error on systems risk. 3. The risk arising from the human in the control loop can be identified and, where required, control measures can be implemented to prevent or mitigate certain errors.
Risk assessment is a tool which companies are required to use to assess their operations. This must take account of the risk associated with the human in the control loop.	

Table 3: Methods for supporting the role of the human

COMMON METHOD	OTHER METHOD
Operating procedures. Quality systems naturally lead to written procedures being required in order to describe what humans in the control loop will do.	**Checklists, diagrammatic procedures and computer-based work procedures.** A frequent problem arises that written procedures may describe the task, but are difficult to use in operating contexts. Checklists, diagrammatic procedures and computer-based work procedures are presentation methods which may be considered in order to improve reliability.

Appendix 2:

POSSIBILITIES FOR CROSS SECTOR COLLABORATION AND LEARNING

There are several existing bodies, activities and projects that have a collaborative and co-ordinating role. These include:

- Human Factors National Advisory Council (HFNAC),
- The Royal Academy of Engineering,
- European Union Thematic networks,
- Royal Aeronautical Society,
- CHECKPOINT,
- COREDATA,
- PRISM,

and conferences dedicated to risk management and safety which gather delegates from many domains.

HFNAC The Human Factors National Advisory Committee (HFNAC) of the Foresight Defence and Aerospace and Systems Panel was established in 1999 to provide advice to government on national priorities for Human Factors research in the Defence and Aerospace industries. Work in the first year sought to understand the UK's capability in Human Factors. During 2001, the NAC has concentrated on developing recommendations of where UK defence and aerospace industry believes the priorities for national R&D spending should lie. These are already influencing the Department of Trade & Industry, Engineering and Physical Sciences Research Council and the Ministry of Defence. Work of the NAC in 2001 has sought to identify trends influencing the future market place for the UK defence and aerospace industries. A sub-committee has prepared a working paper on Protection and Survivability and work to develop a taxonomy of Human Factors topics has progressed.

COREDATA

The COREDATA project is addressing the quantification of the human contribution to risk. Through the project there has been contact with various groups in aviation, airports, air traffic control, vehicle manufacture, nuclear, rail, chemical and offshore oil/gas. This is with the aim of understanding how they deal with the human contribution to risk, particularly from the point of view of structured risk assessments.

PRISM

PRISM is the Process Industries Safety Management Thematic Network on Human Factors. This is a EU funded project. The aim of PRISM is to create an extensive forum within which industry (primarily chemical and pharmaceutical), universities, research centres and practitioners can collaborate to improve the flow of fundamental knowledge and practical experience in human factors and identify areas for improvements and collaborative effort. The project is well supported by both industry and other groups and has the following active focus groups: 'cultural and organisational factors', 'optimising human performance', 'human factors in high demand situations' and 'human factors as part of the engineering design process'. This as an example of a project that aims to promote transferability of skills.

CHECKPOINT

In transport and in other areas of safety critical technology, between 60 and 80% of accidents have Human Error as a major factor. However, there are no agreed minimum standards or means of compliance for considering the vulnerabilities to human error in safety critical systems. In the Aerospace domain, the Regulatory Authorities and Industry have joined forces to evaluate the current certification process. An FAA[1]/JAA[2] Harmonization Working Group will propose - to the Regulatory Authorities - new ways of addressing the vulnerabilities of a design to human error in the Flight Deck certification process. The forum is disseminating the results of National and European research projects and actively involving European stakeholders in a consultative process. No single company, nor the European Joint Aviation Authorities, have the expertise, resources and networks to facilitate such a sustained and co-ordinated European contribution to the HWG.

Appendix 3: References and further reading

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Additional Resources: Bibliographies and Collections of Links to Useful Web-Sites

This document provides a sample of useful web sites related to human factors. It is guaranteed to be incomplete… the web never stands still. However, these sites should provide a useful start.

The **HCI (Human Computer Interaction) Bibliography** provides access to a massive on-line set of abstracts on HCI (over 23,500 records). It also provides lists of reviews of publications and links to many other sites of relevance. http://www.hcibib.org/hci-sites/

ERGOWORLD is a site that exists just to provide links to other sites. It does have a very comprehensive list of links covering topics such as office ergonomics, HCI, air & ground transportation. http://www.interface-analysis.com/ergoworld/index.shtml

Ergonomics Abstracts collects and publishes abstracts related to human factors. This link gives access to an on-line subscription version of the journal. http://tisbe.catchword.com/ergonomics/

Military & Aerospace Organisations

The following sites provide an indication of the scale and nature of efforts that are being put into human factors integration

The **Federal Aviation Authority** has a part of its site related to its human factors programme. This includes documentation that can be downloaded, including a comprehensive Human Factors Design Guide. http://www.tc.faa.gov/act-500/hfl/index.html

NASA have put and continue to put considerable effort into human factors. This gives an overview of their areas of work. http://human-factors.arc.nasa.gov/

The **Human Systems Information Analysis Centre** provides access to scientific and technical information and tools related to human factors integration. For example, it is the source from which copies of the NASA-TLX subjective workload tool can be ordered. http://iac.dtic.mil/hsiac/

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Appendix 4: Working Group membership

Chairman

Mr Terry Morgan FREng	*Tube Lines*

Members

Dr Andrew Belyavin	*QinetiQ*
Ms Elizabeth Carver	*BAE Systems plc*
Mr Vaughan Cole	*Health & Safety Executive*
Mr Peter Eliot	*BP Research Centre*
Mr Hugh Gibson	*University of Birmingham*
Dr Caroline Horbury	*London Underground*
Mr Andrew Leggatt	*BAE Systems plc*
Mr Michael Neale FREng	*Neale Consulting Engineers Ltd*
Dr Gerard Panting	*Medical Protection Society*
Mr John Turnbull FREng	*The International Forum*

Secretariat

Mr Tony Eades	*The Royal Academy of Engineering*
Ms Kiran Babra	*BAE Systems plc*

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1 FAA = Federal Aviation Administration of the U.S. Government.

2 JAA = European Joint Aviation Authorities