The Royal Academy of Engineering

Humans in Complex Engineering Systems

Sharing good practice workshop

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Introduction

The Royal Academy of Engineering report "Risks Posed by Humans in the Control Loop provided the following 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.

- We 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.

- This study 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.

These conclusions seem very significant and to justify a major effort to devise mechanisms to facilitate the identification of best practice in different sectors and to permit these to be transferred and adopted where appropriate. The report's recommendation to hold a "major seminar" was accepted in principle, but it was felt that it would be valuable to gather more evidence in support of the report's findings before taking action on this.

The workshop reported here was designed to do just that. It was structured to have two parts. In the first, experts were invited to present their views and experience. In the second the participants were divided into small discussion groups and invited to look in detail at a particular aspect of the "Human-Technology System Interface".

We were fortunate in finding three speakers who covered the spectrum of sectors identified in the earlier report. Civil Aviation was generally considered to have managed the interface and its complexity remarkably well. The Health Care sector was seen to be struggling to cope with the enormous technology advances being introduced and consequently suffering a number of system failures. The Process Industry was seen to lie somewhere in between. It is a sophisticated and technically competent industry, but incidents like Bhopal, Piper Alpha, Flixborough and questions around the food processing industry cause disquiet.

I hope you enjoy reading this report. Those who attended certainly enjoyed taking part. Needless to say much remains to be done!

John Turnbull FREng
Leader, Academy Risk Project

Executive summary

In January 2001 the Royal Academy of Engineering published a report entitled Risks Posed by Humans in the Control Loop. A working group studied the interface between complex systems involving sophisticated technology and their human controllers. "Human Error" is the most commonly identified cause of accidents involving such systems and there is often debate on the extent to which poor design of the interface was a contributory factor. The study looked across a wide range of sectors. It focused on the design of the interfaces. Do they generally make best use of the respective strengths of humans and machines? It also took into account the organisational and support systems for the human controllers.

The report highlighted major differences in approach in various industries and services. There were differences in almost all aspects including regulation and licensing, the skill base of controllers and their training and monitoring, the approach to hardware design, and the involvement of operators in the design process.

The key recommendation of the report was that there should be much more exchange of experience and practice across sectors and that this should lead to the identification and implementation of best practice.

The report's conclusions seemed potentially to be so significant that it was decided to organise a cross-sectoral workshop to try to verify them and help the Academy decide on follow up action.

50 participants were invited to attend the workshop. They came from a wide range of sectors. Three invited speakers opened the proceedings. They came from Civil Aviation, Process Industry and Healthcare. These presentations confirmed the very different approaches adopted in each sector. Civil Aviation has a well developed regulatory framework, a set of very supportive processes for pilots, air traffic controllers, etc. and a very open and sharing approach to accident investigation and remedial actions. The process industries are generally very technically sophisticated and largely self-regulating. Plant and Control Systems are specific to requirements. Sharing of accident investigations is very limited, but the European industries have set up a specifically process orientated organisation to promote sharing and to develop best practice. The medical field has a huge legacy of history. Modern technology has revolutionised the sector and it is finding it very difficult to adapt to the change. Processes need to be modernised and new organisational approaches have to be developed. The traditional formation of physicians and surgeons does not equip them to address today's requirements.

Following the presentations the participants broke out into small groups to look in detail at the key issues. The body of the report provides a transcript of the report-backs from these groups. Discussion was very lively and a lot of ground was covered. The design of the workshop did not allow much time to craft a polished report and the transcripts generally do not do justice to the quality of the groups' work. But several key themes and conclusions came out of the workshop.

There is a wide variation in practice across sectors. But there are valuable generic issues and factors that are common. While it is not possible to simply copy practice from one sector to another it is possible to learn from experience exchange.

There was widespread agreement that a "learning culture" is crucial for success. Errors always provide a learning opportunity. Excessive emphasis on seeking out someone to blame will discourage the learning.

The importance of team working was frequently emphasised. Modern technology requires a range of skills to implement and operate. In the past a single person could understand and be in total control of operations. Today that is not possible and much more co-operation and sharing are required.

Other key issues identified were the need for regular refresher training and competence testing, a rigorous and critical approach to software application, careful consideration of the impact of job design and skill set, and an awareness that while error tolerant systems have great advantages these very virtues may mask errors that provide the opportunity for learning and improvement.

Feedback from participants was generally very positive. The opportunity to meet with colleagues from different industries and sectors was much appreciated.

Whilst we did not obtain a clear signal that some ongoing structure or organisation was desirable to facilitate exchange on an ongoing basis, equally the idea was not rejected. We clearly need to think more about how best to follow up this workshop. One aspect of the topic that could be a fruitful avenue for further work is the exchange of experience and practice in specifically engineering terms. There is a lot of pressure on engineers to take the lessons of human factors on board in their design of machines and systems. However, it is not clear how this is being done in practice and there may be considerable benefit in establishing a number of good examples of best practice across a number of different environments.

Mr John Turnbull FREng
Leader, Academy Risk Project

Humans in Complex Engineering Systems

Sharing good practice workshop

Chairman: Mr JN Turnbull, FREng

John Turnbull: We have a talent for organising these meetings shortly after some transport incident. This one has been a problem for a few people travelling from the West Country this morning but, judging by their cell phone messages, they should get here.

I have been co-ordinating the Royal Academy of Engineering's Risk Project for a while now. It has been good fun and this event is certainly an important one in progressing our thinking and understanding.

First, let me welcome you here and thank you for coming to a session where you will be required to work. We are looking to you to do the work and provide input to our project.

The overall objective of the Risk Project is to determine how we, as an Academy, can improve the performance of engineers in respect of assessing and managing technical and engineering risk. Through the early phases of the project, it became clear to us that the mood within the profession, and also outside of it, was that engineers and technologists are doing a reasonably good job of improving machinery, in terms of performance and reliability. Motor cars operate much better than they did 50 years ago and civil aviation has a remarkable safety record. Two-engine planes make inter-continental flights etc., etc.,

However, we have also received the message that engineers make a lousy job of their interface with real flesh and blood people. We fail to communicate at all well with society at large and, hence, issues like the GM crop debate, nuclear energy and cell phones go off into some crazy realm beyond all reason. To a large extent, it is felt that this is because we do not communicate as engineers and we leave it to the likes of John Gummer, which does not help. We have therefore been addressing communication as a priority.

The second key issue – which is the agenda for today's meeting – is the interface between the person who is required to control and operate technology, and the technology itself. There is a perception that engineers do a lousy job of designing interfaces that are people-friendly, and which make the best use of people's skills and talents. Thinking again of the civil aviation business, perhaps we have automated all the things that made flying so exciting for Biggles, and his successors are getting turned off through over-zealous application of automation. I was telling a colleague earlier that I have just bought a DVD recorder and I have to say that trying to set it up has defeated me completely.

Part of our response to that has been to set up a working group to produce this report which I hope you have all had the chance to see and read. The working group looked at a number of sectors and saw very different practices across them. Also, more importantly, it came to the conclusion that there was not a great deal of experience exchange between the sectors. It was recognised that the discipline of human factors is undoubtedly uncovering commonalities at what I would call the technical level in the way people behave and the sort of environments which are conducive to good behaviour. But it does not really seem to be permeating to the management layer. It certainly did not seem to be permeating into the way that engineers think and design things.

Their conclusion in that report was that we should look, as an Academy, to see whether we could do something constructive to encourage greater sharing of experience and best practice across the diversity of sectors. I am pleased today that we certainly have quite a diversity of sectors within the room. The only area that we are missing – but you can shout me down if I am wrong – is probably the maritime area. I am wrong! Excellent! I am pleased about that because that is an area with a long tradition that has been revolutionised in terms of technology, crewing levels and all the rest of it. So we have an even broader swathe of sectors here.

We have invited you here for the following reasons:

1. We want you to provide some comparative data to add to that which has already been obtained by the working group and is contained within the report, on how the different sectors approach the issues.
2. We want to obtain your insight and feel into just how well the current interfaces are actually designed and operated. Are they really making the best of the human controller and the technology?
3. We want to test the conclusion within that report that there is value in a methodical exchange of experience and best practice.
4. We would like to hear your views on where we go from here. At the end of the day, it may well be that you will persuade us that exchange is valuable, but that it is actually already going on, so there is nothing more that needs to be done.

We really want to test the conclusion that our group reached, which is that there is inadequate exchange of experience and best practice, and that there are inadequate mechanisms in place to do that.

After our speakers make their presentations, I will talk about the break-out groups and how that will work. Our first speaker is Peter Brooker from Cranfield who is expert in the civil aviation field; then we will hear from Tony Giddings about the medical world and the changing operating theatre – and certainly what is going on in the medical world is dramatic these days.

Finally, we have Lee Alford, a fellow process man – my background is in the process industry. Lee has played a key part in the initiative taken by the process industry, which ranges from Walls ice cream, to gas-fired power stations, to refineries. That particular sector set up an exchange mechanism called PRISM, so Lee has some experience of how to encourage people to exchange experience, and how valuable or otherwise that sort of exchange can be.

Peter has to leave early to attend another meeting. I had intended to take questions at the end of the three presentations, but if there are any questions or clarifications related to Peter's presentation we will take them immediately after he has spoken so that he can fulfil his other obligations. Peter assures me that he will be able to come back for our afternoon closing session.

The Civil Aviation Approach

Professor Peter Brooker
CAA Professor of Air Traffic Management & Environmental Policy
Cranfield University, School of Engineering

Thank you for inviting me – I hope this will be a successful day. The title of this presentation is straightforward, but I love checking the dictionary, and I find that 'engineering' comes from the Latin word ingenium, meaning skill. Engineering design is a process that involves people's skills – there are actually people involved in engineering – and so does the regulation of transport safety. The human's contribution is not just operational and we have to think of the very big picture of design and regulation. Given the time available, I will only give a little background and state a few very simple, general points, and then give a couple of interesting examples which you might like to think about later.

Civil aviation features
Here are some features of civil aviation. Safety is the top priority and that also drives the need for effective regulation and licensing. However, I would like you to note that some of the elements of the aviation system are price driven, because there are markets with competition between different organisations. So there is a utilisation of resources that reflects markets and safety is an element that will have to come into that.

Civil aviation safety targets
We all agree that it is absolutely essential to design aviation systems that are safe. By 'safe', we tend to use safety targets. These are some safety targets that we use when we are trying to improve or introduce new systems of various types. The main point here is that we have to use the superscript font for the numbers because they are very demanding – incredibly demanding – targets. You are far safer travelling by air than the risk of getting mugged on the Piccadilly Line, going to Heathrow. The difficulty with anything new is the work programme that you have to go through, to prove that it is safe. These targets are such that you actually have to have a great understanding of what the new system will be like – what its failure modes are, and what sorts of things you have to protect against.
Human-centred design factors

At least one person here will be horrified by this slide – the professional human factors person. This is a human-centred design in one slide. It has taken over a century, if you track back – and I have talked to some of my human factors friends and they can point to the various insights that people have had over the years. This is a distillation of those insights. Some of them seem pretty obvious now, but that is probably life – what seems obvious to us was not obvious to people 10, 20 or 50 years ago. There has been a great deal of learning from accidents, obviously, and many advances have been made in understanding how people do things, the human performance, particularly ergonomics and cognitive psychology. They are the sort of principles that you have to think about when you are designing anything.

Some civil aviation risk categories
Civil aviation covers many kinds of risk. I will not deal with security but I will give one example of aviation safety and one example of air traffic management (ATM) safety. ATM is the most complex aspect from a human-centred point of view, as I will illustrate later.

Loosely- and tightly-coupled systems
One of the key concepts that one has to worry about when talking about human systems is the fact that there are big differences between tightly-coupled and loosely-coupled systems. Tightly-coupled systems can be modelled with confidence – you can get data on what happens in terms of sub-system failures. Internal aircraft systems – the engines, computing and electronics – are largely tightly-coupled systems.

The second category, loosely-coupled – and obviously this is a great simplification because there are mixtures in different systems – relies on safety defences in depth. Thus, you have a multiplicity of formal, technical and human safety defensive barriers. You have these safety layers that deliver the necessary safety. The problem with loosely-coupled sub-systems is that you cannot usually model them quantitatively in a clearly precise fashion in terms of the frequency of specific errors and failure types. However, you will have probabilistic statements about what people might do in certain circumstances. That is where some of the perspective comes in – there is the very old style of engineering

that people know, where you have lots of failure rates of bits of kit, and you multiply the numbers together, but it is much more complex when you have loosely-coupled systems, because there are people in them usually, and people are adaptive. We have adaptive behaviour.

Aspects of controller workload
I hope this is readable – it is rather a busy slide. If you talk about air traffic management, at the heart of that system currently, and for quite a long while – for decades – our controllers, and the work that has to be done when they handle aircraft, moving them from airport to airspace and back to airport again – this is intended to do no more than show how complex that control workload can be. I do not think that there are systems that are more complex than those of air traffic controllers in terms of normal operations.

Workload is very difficult to define. One definition I have is that it is '...the amount of effort, both physical and psychological, expended in response to system demands and also in accordance with the operator's internal standard of performance.' - which is pretty static. Workload is a multi-dimensional concept, with many elements in there to do with the difficulty of different tasks and the effort that will be required – not so much physical for air traffic control, but certainly mental – that has to be brought to bear. There is a personal dimension there, because people do not come into work every day feeling 100 per cent. Controllers are not supposed to drink, and I do not think many of them do in the UK, but people still do not always feel wonderful everyday.

The European ATM system – I
I will talk about the European air traffic management system. One of the great things about being at Cranfield is that you have a full set of Flight magazines, so I can go and read about all the accidents over the years. The first mid-air collision was in 1922 and happened in Beauvais, about 60 miles north of Paris, between a British aircraft and a French aircraft – so at least we lead on something!

Air traffic controllers are important decision-makers in the whole system. They communicate by radio telephony and use flight plans agreed with pilots. They monitor highly processed radar data – you should go and look at a radar screen in an air traffic control centre. It is very processed data which is presented in a very succinct and ergonomically designed fashion. You have those sort of dataflows that are embedded in safety structures, and you have well-defined airspace, which is called 'controlled' airspace, because people have to operate on instruments and they have to operate with particular separation rules. There are formal rules for air traffic control. I have not brought with me today a copy of any of the manuals of air traffic control – they are called Manuals of Air Traffic Services and are used by units. These are very large documents which lay down very precise instructions for almost anything you could ever think of.

The European ATM system – II
Navigation has improved enormously. There are people here who are experts on satellite navigation, who will tell you how wonderful satellite navigation is. In the UK, we have also brought in conflict alert systems of various types. There are short-term conflict alerts – STCA – which are systems based on doing things on the ground, so that the control is able to detect the possibility of a collision.

Commercial aircraft now carry TCAS (Traffic alert and Collision Avoidance Systems) on board, and these work by variance in radar. They warn against collisions with nearby aircraft. These are the sort of additional safety defensive layers that have been evolved in this loosely-coupled ATM system – loosely-coupled from a design point of view. 'Loose' does not indicate sloppy, but it is 'loose' in terms of the fact that you have adaptive responses.

We have evolved this operational concept over a great many years and it is an evolutionary process in many senses. It is overlaid, with new technology added on to the previous concepts, rather than being a clean sheet new design. These sorts of things mean that you actually have real safety achievements over the years, to which we have already alluded. Aviation is seen as a transport area that has succeeded. I have lots of graphs, with which I will not bore you, but if you look at the accident statistics and the 1950s and early 1960s, they were horrible compared to what they are now. The accident rate has decreased dramatically in the period of the sixties and seventies and it is still reducing.

One fact to bear in mind is that, if you take the world-wide statistic, typically about 1500 people die each year due to aviation accidents. Of course, 1500 is too many, but it is 1500 world-wide, compared to about 3,000 people who die every year in the UK in road accidents. That is a measure of an achievement.

The Ansett Dash 8 fatal accident – I
What can we learn from accidents and improve aviation safety? This accident occurred in 1995, and it looks very simple: an aircraft crashed on landing. I have taken this from the original press briefing that came out about it in 1995, which was on the net. What lessons were learned from this? The lessons were far more complicated and far more informative to human practice.

The Ansett Dash 8 fatal accident - II
One of the problems is that this accident happened in New Zealand and one of the major factors was that New Zealand was a long way from the USA. They never practised the simulator training. Those are the points that you have to think about, concerning human-centred design. There are cost and organisation problems, and operational safety problems. There are fatigue problems, and regulatory problems. One of the interesting points about regulation is how far regulators should actually believe what people tell them. You cannot actually have an inspector going around every day, checking that what actually goes on is what they tell you goes on. Where is the balance?

There is something in horrible colour at the bottom of this slide, saying that the airline that had this accident went into liquidation. That was the cost-pressure problem that led to the safety department being involved, because nobody was monitoring faults.

The training issue is absolutely vital. We have already heard, in terms of other transport modes and industry modes, that you actually have to train people. Training is part of human factors – part of making sure that you design the system to fit the people who are in it, when they are trained properly.

The components of ATM safety
If you look at ATM safety, you will see that it is not just the providers – of air traffic control, for example – who take responsibility for preventing accidents. Here, I have put in ATC as air traffic control; CNS is communications, navigation and surveillance systems; DP is all the data processing and information flows. There are 'system guardians', as I call them, that are distinct from the actual providers of the service. The Government sets up the regulatory regime and the airspace has to be designed to accommodate all of the users. There are commercial flights, military flights and general aviations – private pilots. The safety regulator has to be confident that everything works properly, and we go back to the definition of safety regulation: "To require enterprises to take proper account of the hazards to which they expose people."

The Überlingen mid-air collision – I
I have given you an example of an aviation accident, but this is an ATM accident. This is the most famous, horrendous one,that happened a couple of years ago in a place called Überlingen, on the Swiss/German border. It took them two years to produce the accident report on this. It all looks very simple on this slide, doesn't it? This is just a narrative, taken from the web report, in the newspaper the day afterwards. That is the sort of thing that they said. It happened, but what did it actually mean? It was a horrific tragedy.

The Überlingen mid-air collision – II
What were the human elements? Here is a selection of human-related elements. There were several technical problems too – technical problems related to regulation and operations. The STCA was not functioning properly and some bright engineer was changing something. The telephone network was out of order, and that was a factor. So there is a big regulatory issue there.

From the accident report, the controller tried extremely hard to sort everything out. If you read the accident report, you can read the transcript and see the sorts of things the guy was doing. He was trying incredibly hard to solve the problem but the situation in which he had been put just did not give him any chance to resolve matters. Too many things went wrong at the same time. He got the blame and in fact he was murdered by somebody who was said to be a relative of several passengers.

That was my final slide. Generally, one is supposed to finish a presentation with something upbeat but I am afraid I cannot do that. This is the sort of game we are in. We are trying to save people's lives and we are trying to make sure that systems are designed so that human beings can work well in them. This workshop covers real, important issues. Thank you very much.

Royal Academy of Engineering Workshop
10 November 2004

HUMANS IN COMPLEX ENGINEERING SYSTEMS The Civil Aviation Approach

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Civil Aviation Features

- Safety – agreed top priority, learning organisations
- Professional regulatory regime
- State licences for airports, airlines, controllers, pilots, engineers, etc
- Opportunities for and competition in the industry - market benefits to users
- 'Best practice' in meeting environmental & sustainable development goals

2

Civil Aviation Safety Targets

- 1.5×10^{-8} fatal aircraft accidents per flying hour for mid-air collisions – of any type for all causes – for en route flight in controlled airspace.
- 10^{-9} catastrophic aircraft accidents per flying hour is taken as an acceptable risk rate for any single failure condition

These targets are incredibly demanding in terms of design, safety modelling and performance monitoring

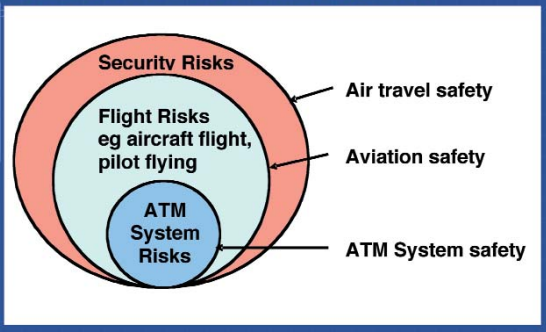
3

Human-centred Design Factors (in one slide!)

- Key design driver is capabilities & deficiencies of end user
- People are limited capacity information processors
- People inherently make some mistakes/errors
- People must work with other people
- People are different
- People cannot easily be modified
- Must fit the person to the job and the job to the person
- Must learn from system failures

4

Some Civil Aviation risk categories



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HUMANS IN COMPLEX ENGINEERING SYSTEMS The Civil Aviation Approach

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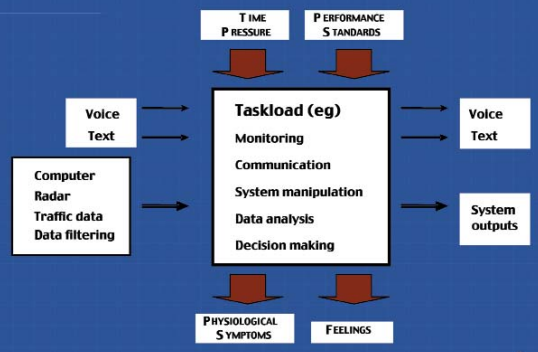
Aspects of Controller Workload



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The European ATM System - I

- Controllers and pilots – people are an integral part of the whole system
- Formal Rules for the control of traffic
- Radio Telephony
- Controlled Airspace – sectors handled by controller teams
- Flight Progress Information – flight plan computing
- Radar – processed Secondary Surveillance Radar (SSR) – displayed aircraft symbols complemented by callsign/height information

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The European ATM System - II

- Computer Processing of radar and flight data.
- High Quality Aircraft Navigation – VOR/DME to Inertial Systems through to satellite-based aids
- Conflict Alert (STCA) – the computer processing system can analyse SSR tracks to predict if aircraft might come into close proximity and warn the controller by radar screen messages.
- Traffic alert and Collision Avoidance System (TCAS) – on board collision avoidance system based on detection of other aircraft in the vicinity carrying SSR transponders

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The Ansett Dash 8 Fatal Accident - I

- 9th June 1995
- Flight AN703 approached Palmerston airport, NZ
- Aircraft De Havilland DHC-8-102 – 'Dash 8'
- The undercarriage stuck
- The aircraft descended below safe altitude
- It crashed on a ridge
- 4 people died

How? Why?

10

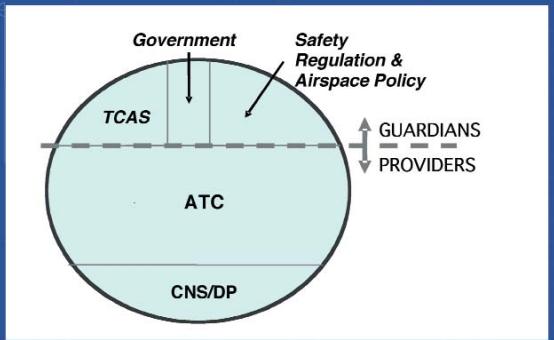
The Ansett Dash 8 Fatal Accident - II How? Why? – some human elements

- Emergency training never practised – nearest simulator in Seattle
- Ansett Safety Department/Manager had been abolished – so nobody to monitor recurring equipment faults
- Co-pilot never practised undercarriage checklist
- Fatigue due to early start of duty day
- Regulator believed what Ansett said about training

Ansett New Zealand went into receivership & liquidation in 2001

11

Components of ATM System safety



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The Überlingen Mid-air collision - I

- 1st July 2002
- Flights Bergamo to Brussels and Munich to Barcelona
- B757 and Tupolev-154
- Aircraft on converging course at flight level 36,000 feet
- Air traffic control + STCA + TCAS did not resolve the conflict
- The aircraft crashed
- All the people on the aircraft died

How? Why?

13

The Überlingen Mid-air collision – II
How? Why? – some human elements

- Regulator allowed (?) just one controller working the radar screen
- Controller had to monitor two different display consoles, separated by over a metre
- Controller became preoccupied handling the approach of an aircraft to an airport
- Controller did not realise phone system was not functioning
- Regulators did not ensure that pilots would respond to TCAS alerts consistently

Controller murdered

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Questions & Answers

Professor Ken Hambleton: We are talking about interchange across different sectors of information and safety issues. Do you believe that there is sufficient interchange across various international airlines, or international air traffic control systems? Or should charity begin at home?

Peter Brooker: You can always do better. The safety people and certainly the airline people – in fact, there are not many manufacturers around now, but Boeing and Airbus seem to talk to each other about things. The air traffic control people, the safety people, meet very frequently. The International Civil Aviation Organisation in Montreal has regular meetings all of the time about various things and the major developed states go to those.

Things have improved a good deal in recent years. There was certainly a problem 10 to 15 years ago, when the Russians did not come to these things, and we did not know what went on in Russia, and there was similarly a problem with the Chinese – and there may still be a problem with interchange with the Chinese.

Professor Hambleton: I heard a talk some years ago, comparing the Australian situation with the European one. It seemed remarkably different in terms of the people issues.

Peter Brooker: I did some work for the New Zealand authority recently and one of their big risk areas is tourism. They have people taken by helicopter to inaccessible places, for leisure. We have quite a strong distinction between commercial aviation and general aviation by private pilots but, if you are in Australia or New Zealand, there is much more adventure tourism. The helicopter accident rate in New Zealand is quite high. They have a problem with Australia – which, I have just noticed, is quite big – in that they do not have radar coverage across most of it. They are therefore having to find ways of dealing with that. Radar is wonderful.

Vaughan Cole: You referred to looseness and tightness of coupled systems. How do you measure the looseness and tightness?

Peter Brooker: That is a good question. The distinction goes back to organisational theory, in fact, and there are some references in the hand-out. There is a fair amount of work by a man called Perrow, on various types of accidents in systems. He was interested in the process industry.

You find out what kind of system you have when you try to design it. If you have a piece of wire that you stick somewhere,that is going to bend at some point – if it is a "Comet", and there is going to be some metal fatigue. Then you are getting a bit of a guideline as you try to make up a system. If you have an air traffic controller in there, and they can do lots of different things, then the time that it takes for a controller to do something can be very variable. There can be many other things that an air traffic controller is doing, so that is a loose one.

You think about that when you try to design it, although there are no simple parameters in there. If you have human beings involved, you tend to have loosely-coupled ones. That goes back to the point that was made about manning systems – one of the things that you have to worry about, going back to the human factors design criteria, is that if you design it so that human beings are simply a switch to do things, there are then some problems in there. You have to have enough variety for the person to do things, but you must not have so much variety that the responses in the system become confused and mixed up. That is a good question.

Vaughan Cole: So the challenge is around humans.

Peter Brooker: If you look at aviation accidents and incidents over the years, there is a human dimension in almost every one. You have Jason sitting in front of you, an ex-Cranfield person, who knows about the aviation side. I know about the ATM ones. If you look at the incidents, you have near mid-air collisions, and if you look at most of the near mid-air collisions, they do not occur because the radar has gone wrong; they do not occur because the navigation equipment has gone wrong; and they do not occur because there is any problem about surveillance. They occur because a human being – a pilot or a controller – has miscommunicated something, or they have just lost the picture of what is going on. That is the sort of thing that you have to watch for.

Speaker: Related to that, how then do you stop some of these faults? They are very obvious in retrospect, but the key question is, how do you spot them in advance and how do you deal with those? What systems do you have, or what are people using, to spot these things in advance?

Peter Brooker: This is something that I am very interested in. We are in this game and, if I had a success, it would be to spot something from something happening now that would prevent something happening in a year's time or five year's time. Traditionally, in the old days, you had a great many accidents. The "Comet" is the example I would give and there were at least three "Comet" crashes because of various sorts of fatigue. However, once the people down in Farnborough investigated the aeroplane, they could see the problem and they would know what to do.

Now, you do not have the accidents, you have to look at incidents. You can see how complicated the whole thing is, and you finish up with a lot of apparently improbable events happening. The only solution that people come to is that they have to make your safety defence learning as effective as possible. You have to make it so that you have protection devices, so that your short-term conflict alert is there, so that the controller can detect the potential collision. You have to have it so that your on-board collision avoidance system, TCAS, is effective. Much of the interest over the last 15 years has gone into making those conflict alert systems as effective as possible. So you are putting in the safety: you are trying to ensure that you have sensible human design in the whole scheme, but you are putting in extra layers.

John Turnbull: I will stop it there because Peter has to leave us. However, that question is a key one and I have to say that part of the object of today, in bringing people together from various disciplines, is to exchange experience across disciplines. Had you asked a chemical engineer about the "Comet" design he would have said, 'I have never seen a vessel subject to pressure variation with a square manhole on it. They are always round.'

Let us move on now, to hear about the "Changing Operating Theatre." If you do not die in the ambulance taking you to the hospital, Tony will explain what happens when you get there.

The Changing Operating Theatre

Mr Tony Giddings
National Clinical Assessment Authority
Surgical Advisor to NHS Modernisation Agency

Thank you for inviting me – this is a fascinating subject area in which we are extremely interested. In the 15 or so minutes available to me, I will suggest pointers for our discussion, rather than to flesh out in detail a number of these interesting areas.

Let us go on a little journey, starting by looking at the subject headings that I have chosen for these discussions. First, technological opportunity and complexity; then workforce and training; safety and behaviour; trust and judgment; regulation and licensing; and the achievements and challenges in our surgical and medical fields.

We will begin at the beginning of the 20th century, when an operating theatre like this was a model of starched authority. The systems were very simple and the objective – which was doing a dangerous operation with had no alternative – was pretty easy for us.

In the eighties, we had moved on. In this photo, we can see the complex anaesthetic instrumentation and, for the first time, some measurement of what was actually happening to the physiology of the patient during our intervention. This is open surgery, technically perhaps rather primitive, but for the first time this is a study module.

And now surgery has moved on and this photo shows a micro-laryngoscopy, using micro-techniques, with anaesthesia. Once again, we are now getting monitoring data of what is actually happening, which might explain some of our results.

The next revolution was 3D imaging, CT and MR, which enables us to construct complex anatomical information, like the relationship of this tumour to its adjacent blood vessels. One can thereby make interactive, real-time assessments of where you are, protecting vital adjacent structures and controlling some degree of human fallibility.

Here we are, in the robotic era, with some potential for active feedback from the surgeon's hand movements – monitoring, on a real-time basis, the movement of those instruments when they are in a dangerous territory. I will not tell you a great deal about technology because you know more than I. What I shall talk about, however, is the effect of that technology on us.

Technical opportunity & complexity from:
As I have explained, we have moved from what you might call essential indicators for operations, like peritonitis and haemorrhage, to rather more elective ones. We have moved from the hand and eye, to the machine-assist. We started with a few simple tools and a number of bits of string, and we now have a rather complex one. We started with a small repertoire, but it is now large. We have a high risk for the patient initially, but now that risk is translated into a much lower one. Years ago, there was rather a low risk for a bad surgeon being discovered but that is no longer the case. There was initially clear, uni-professional patriarchal authority.
Technical opportunity & complexity to:

We now have elective indications for operations, and complex instruments and prostheses. We have stereo-tactic information and robotic assistance. We have a vast repertoire. We have a low risk for patients, relatively speaking, and a high risk for a surgeon who is not performing well. We have uncertain multi-professional authority, which would merit a whole day's debate on its own. You will receive a copy of these slides, which I hope will make it easier to follow what is a rather crowded presentation.
Workforce and training, from

If we review our workforce and training, similarly we have gone from a situation with very few surgeons in this country, according to national and international comparisons. We have gone from the concept of independent practice; training given for life; general skills; tests of knowledge and little quality assurance –

Workforce and training, to
- to a system now where we have still rather few surgeons for the complexity that we deal with, but an increasing number of non-surgical and, in some cases, non-medically qualified surgical practitioners to help. We have team practice, which is our modern model. There is the need for constant re-training, and a web-based curriculum which is constantly updated. We have specialist skills and the scrutiny of outcome – which is what we are all interested in as potential patients – performance assessment, and an attempt at revalidation. As I will show later, that is a pretty difficult thing to do with surgeons.

Technical competence is essential
We you start to measure things, there are some surprises. One of the interesting things we found, looking at knot tying by experienced and inexperienced surgeons, was that there was an astonishing variation in objective measurement of the skill and performance of this task.

Further, when we looked at the training courses that we were running, there was an astonishing variation in the effectiveness of those training courses to deliver their stated objectives. In this motion analysis device, which was measuring how surgeons' hands worked, it showed that one in three courses we ran to make them better made no difference whatever.

Similarly, when we looked at videos of people operating, which you would think was a pretty good way to see whether they were doing a good job, we found that that objective analysis missed a great deal of information on which the safety of that operation depended – namely, all the non-technical skills which are so important for safety.

Safety and behaviour
The Institute of Medicine Crossing the Quality Chasm report in 2001 articulated international concerns about safety in these complex systems.

> "Health care harms too frequently and routinely fails to deliver its potential benefits. Indeed between the health care that we now have and the health care that we could have lies not just a gap, but a chasm."

Is that still a problem in 2004?

> "A prospective surgical ward study ...."

This is rather detailed and you only need to look at the area towards the bottom of the slide, which indicates that 52% of the harmful events that were observed were preventable. That is not a terribly good record for anyone who feels that they may need to go into hospital.

The Kennedy Report
There was a watershed in the publication of the Kennedy Report. This is an enormous document which will take you a weekend to read, but which is well worth it if you are interested in the area. What we learned from Kennedy was the whole systems approach to medical safety and surgical performance. It identified shortcomings in all the systems involved, in the infrastructure, and indeed in the individuals concerned. In his words, 'good people doing bad things'.

Learning from Bristol
We learned that doing your best is essential but not enough, and that good performance required the agreed objectives – which, strangely, are often lacking in healthcare; an effective team, which usually does not exist; and appropriate systems which we know about but do not have.

We sometimes also looked at the major catastrophes which have been identified for us by the friendly press. We are sometimes given this sort of stimulus to our improvement. 'Doctors removed the wrong kidney' – and you may remember this event in Wales. This was a sudden, catastrophic event, where life was lost and people's reputations were indelibly destroyed.

The comparison was made with the Kegworth pilots who shut down the wrong engine. This kind of catastrophic single event, often ascribed to one person's human failure, a primitive analysis, applies in medicine. This surgeon was destroyed and the patient lost his life, the family suffered a bereavement but it was all preventable.

Why? Well, there was one person in that theatre who knew they were taking out the wrong kidney. It was the medical student, a girl, who said, 'You are doing that, and it is not correct', but everyone ignored her. There is a lesson there.

Trial for manslaughter June 2002

What is even more frightening is that, at the trial of this surgeon for manslaughter, the Sister said, 'I would not have looked to see if it was a left or a right-sided operation, because both would need the same equipment.' That is an extraordinary, and rather pathetic indictment, of the concept of team-working in the health service.

Here is an operation on a varicose vein in the groin: simple, routine and frequent, and usually not dangerous. A colleague who I know well, divided and removed the superficial femoral artery, an adjacent vessel, in a 23-year old girl. You might ask why that should happen. The surgeons are very experienced and I would be happy for them to operate on me. It has to do with cognitive psychology and we have learned a little about that already today.

Information processing

Generally, the reason is to help us to understand the difference between our conscious workspace, which is small and labour intensive, and the long-term memory, the skills of which and the automation it provides, enable us to do complex things, on autopilot, effortlessly – but it needs monitoring.

This is Jim's diagram of the attention torch, which can be distracted. It can have its lights dimmed or it may take a habit trap path. Then, a good surgeon can make a desperate error. If you work in an operating theatre which does not have proper systems assurance, where people are distracted – there is too much music and loose talk, where the light is bad, or you have an inexperienced assistant, or the person who is perhaps scrubbed has never seen the operation before – this is the sort of thing that puts you at risk.

Root cause analysis has been used a great deal in engineering, aviation and so on. I will not trouble you with the details of this but you can take it from me that there are 40 preventable steps which led to a doctor being charged with manslaughter for erroneously injecting vincristine into the spine of a child – who died. Was the truth told in the court that day? I think not, because this is like a Greek tragedy and, if you set up a system to achieve that result – and here is the definition of it – it will do so, predictably. You need to pay attention to that system.

You may think that, if we were to put in a checklist to deal with each one of those 40 risks, we would have utopia, but not so. This is a child who, again, died of respiratory arrest, because the plastic cap, rather like a biro cover, from an infusion device, had got stuck in the catheter mount of the anaesthetic tubing, in which it was invisible and totally obstructive. The police mounted a murder inquiry and 13 other devices were identified with that fault and it was not until a forensic analysis took place, shaking loose discarded caps with anaesthetic tubing in a draw, that the potential for this accident was defined and the nature of the fault was discovered. We will never have a checklist for accidents like that which have not happened.

My message to you will be to be like Sherlock Holmes and to use your vigilance, which is a key quality, your intuitive and professional skills and common sense, in order to prevent happening what you have not yet conceived.

Behavioural markers of surgical excellence

If you want evidence how important behaviour and these skills are, this is a landmark study done by Marc de Leval at Great Ormond Street on the cardiac switch operation, which is a high-risk procedure in newly born children. Sixteen cardiac surgeons were studied and there was a detailed analysis of three aspects of that team's performance. I will not go through the details, for lack of time, but the surgeons were assessed on their skill and performance. The team as a whole was assessed and then the system was assessed, for planning and organisation.

The results were astonishing. In the National Health Service, we have these data which show the performance of 16 highly trained and highly motivated cardiac surgeons, doing this dangerous operation in the post-Bristol phase when, clearly, they were under the spotlight. When you look at their major errors, what is astonishing is the extraordinary variety of performance – not only in the errors committed, as indicated in the first bar, representing each of their performance, but in the second bar, which is the number that were recognised and corrected. We know that we all make errors, but what matters is recognition and correction.

There is a further lesson from this study. These were minor errors – people dropped something, or they had the wrong instrument; or someone had interrupted them with a phone call. Were they important? In everyday life, in health care, we do not think they are and we ignore the risk. Actually, what this study shows is that if there are more than five or six of those minor, unimportant events in one case, then they produce death and delay in recovery. This is the data from this study, which you may care to look at in more detail.

Team working and performance in the NHS

Thus, teamworking and performance contributes to patient survival, if it is an effective the team. The reality is that most of the NHS staff think that they work in teams but objective studies show that less than half work in effective teams, as shown by productivity gains and service benefits. Dysfunctional teams are common, self-orientated and inert and I have to tell you that successful remediation is unlikely without new personnel.

The work of the NCAA

I am a non-executive director of the National Clinical Assessment Authority – which you may wish to discuss later. This is a special health authority, running for two and a half years, assessing doctors' performance. This is a very difficult job.

Assessment concerns

In over 1,000 doctors assessed that, in many, there is a concern about their clinical capability, and there often is a sentinel event which attracts attention. However, in some it is only behaviour, while a combination of behaviour and other concerns accounts for some 65 per cent of referrals. The message is that behaviour is important and, if you have one problem, you will get the other.

This is the key: that the best surgeons, like Sherlock Holmes, can anticipate potential pitfalls better than their colleagues.

Trust

I will briefly talk about trust and judgment. We must trust our doctors, as doctors must trust their colleagues to deliver service to their patients. However, it is said to be in decline and it is no longer seen to be sufficient, particularly by governments, in complex systems. It is increasingly replaced by a culture of suspicion and an increased desire for a guarantee.

But ...

However, as Onora O'Neill said to us in her landmark Reith Lectures, we ultimately have to trust that guarantee, or regulatory, or system. Trust, like morale, is very domain specific, and we have to look at what we do, to understand its operation, and not at what is said. Despite the widespread allegation that trust is declining, most people get on aeroplanes and most people sign their consent forms for operations.

The question of trust

The question of trust which involves transparency, or opacity and betrayal – in the case of Bristol –

- is much more to do with the opacity than transparency, and the real problem is secrecy. It is in generating that openness in professional exchange, and frankness with members of the public, that we have one of our greatest professional challenges.

Finally, in the surgical field, I am quoting TS Elliot:

"The last temptation is the greatest treason
To do the right deed for the wrong reason."

It is true to say that the surgeon's criteria for success are not always matched by the patient's experience.

Functional outcome after open AAA

This is a very simple study: looking at functional outcome after open aortic aneurysm repair. This is a big operation for a dangerous condition. This study was done in a world-class unit and they thought they had done marvellously by doing this dangerous operation with a mortality rate of only four per cent. But detailed inquiry showed that 33 per cent of their patients had reduced functional activity in the long term and 18 per cent would not have done it again – even though the underlying condition poses the risk of sudden death from rupture of the major blood vessel.

Medical practice I

Finally, we are moving into regulation and licensing. For 150 years we were guided by the Medical Act of 1858, where we had independent practice. That was enshrined in the 1946 Act and, even when I qualified, we were given advice by the GMC never to criticise a colleague, even if they were incompetent.

Medical practice II
Now, it is different. We have been through Bristol and we have been through many different cultural changes, including in 1999 the chief executive's statutory responsibility for the standards of clinical practice.

Regulation
Regulation has increased under this Government because GMC is now overseen by the Council for the Regulation of Healthcare Professionals. The Royal Colleges – 19 of them, providing all your postgraduate training – are now overseen by this embryonic, all-singing, all-dancing body, which should have gone live six months ago, but remains embryonic. It has lost one chairman and one chief executive, and is now suddenly realising the enormous task which this wizard idea, put out by Government, that there should be effective regulation of medical post-graduate training, has given us. It is a proper job to do but it is a huge job to achieve.

Achievements
In conclusion, what are our achievements and challenges in surgery? Think of the National Health and remember that it is the largest and most equitable healthcare system in the world, and mostly it still works. The relief of pain and fear is, in this country, tangible. We have advanced in knowledge beyond individual benefit. By that I mean that we do liver transplants at King's, which is fantastic, but the number who benefit are few. However, worldwide, the benefit from that knowledge is enormous. We have set the stage for further advances.

Challenges
As I have indicated, our challenges are to improve the safety, effectiveness and appropriateness of what we do; the training and assessment; and embedding multi-disciplinary team working in our health service, of 1.3 million workers. Importantly, we must resolve the political and professional dissonance.

Political: professional dissonance
To finish, here is one simple example of why that is important. Alan Milburn insisted after the Bristol affair that there was a political imperative to publish the results of individual cardiac surgeons by April 2004. That shows a fundamental political misunderstanding of where quality is. The profession has a requirement to publish these results for individual cardiac surgical teams, because it is the team that makes it safe or dangerous. It is that dissonance between the profession and politics that we must really work at, because there is considerable naivety situated in a large building not very far from here.

Hey Groves 1908
Returning very briefly to Bristol, in 1908 the then professor, Ernest Hey Groves, wrote up the mortality of these operations – hideous figures: gastrectomy, 44 per cent; resection of rectum 24 per cent; prostatectomy 23.5 per cent and appendicectomy, nine per cent chance of death.
Hey Groves 1908

In a one-and-a-half page article, he proposed a central authority, a committee, a nomenclature, an inquiry, a record of the facts and statistical analysis of results, to find out how to do better. Ninety-six years later, we have published the first report which can produce real evidence in that way.

It is a paradox that, in these days, when Goya did this wonderful picture of the doctor, who was wearing this imperial coat of unquestioned authority, he had at his disposal almost nothing that worked, and almost no knowledge that could be tested, and yet his authority was undisputed. We now have power beyond our imagination; authority which is constantly challenged, and a huge task to do what is required with the opportunities that we have.

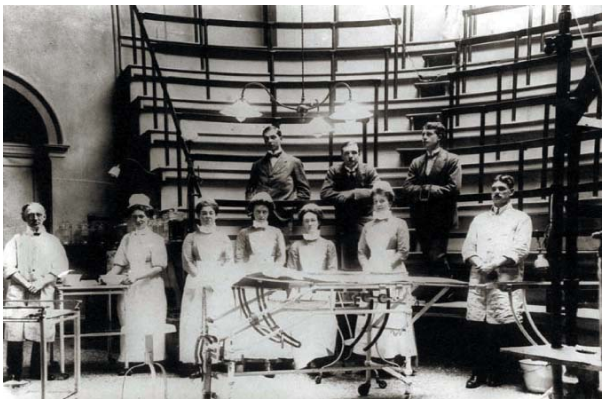
Thank you.
John Turnbull: Thank you, Tony. If anyone in the room was motivated not to share before he came in, that presentation will surely have removed the inhibition to share experience across the barriers.

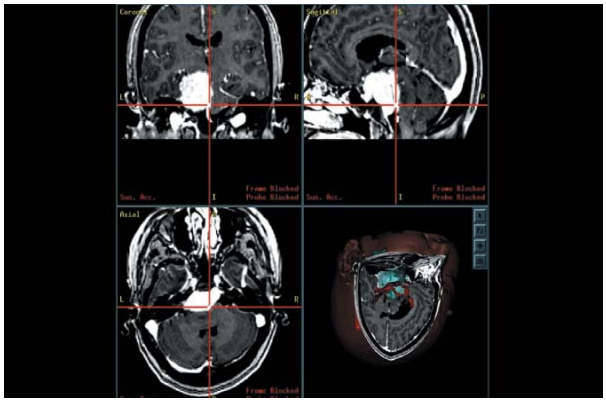
Lee Alford will tell us about experience and knowledge sharing in the broad sector of the process industry.

The Changing Operating Theatre

Tony Giddings
Consultant Surgeon

Technological opportunity and complexity
Workforce and training
Safety and behaviour
Trust and judgement
Regulation and licensing
Achievements and challenges





Technical Opportunity & Complexity

From

- Essential indications
- Hand and eye
- Few simple tools
- Small repertoire
- High risk for patient
- Low risk for surgeon
- Clear uni professional patriarchal authority

To

- Elective indications
- Many complex instruments & prostheses
- Stereo-tactic information
- Robotic assistance
- Vast repertoire
- Low risk for patient
- High risk for surgeon
- Uncertain multi professional authority

Workforce and Training

From

- Few surgeons
- Independent practice
- Training for life
- General skills
- Tests of knowledge
- Little quality assurance

To

- Few surgeons + practitioners
- Team practice
- Constant retraining
- Web based curriculum
- Specialist skills
- Outcome scrutiny
- Performance assessment
- Revalidation

Technical Competence is Essential

The large range of data obtained for the senior groups suggests a need for training at all levels in one of the most basic tasks – knot tying at depth

Evaluation of knot tying at depth between general surgeons and urologists. J Shah et al. Ann R Coll Surg Eng 2004; 86: 381–382

Assessment of psychomotor skills acquisition during laparoscopic cholecystectomy courses.

R Aggarwal et al Br J Surg 91, Suppl 1, 61;2004

Motion analysis device (pathology, number of movements, time taken)

One of three courses showed no improvement

The reliability of the Operative Competence Assessment by video and direct observation

CG Burt et al. Br J Surg 91, Suppl 1, 133;2004

Hernia repair study.

Additional information from direct observation is necessary

Safety and Behaviour

'Health care harms too frequently and routinely fails to deliver its potential benefits. Indeed between the health care that we now have and the healthcare that we could have lies not just a gap, but a chasm.

IOM Crossing the Quality Chasm 2001

A prospective study of patient harm in general surgery.

A Kaul and P McCulloch. Br J Surg 91, Suppl 1, 143; 2004

Prospective surgical ward study over 1 month: identifying deviations from predicted outcome.

117 patients (82 emergency, 35 elective) 49% had 1 or more unexpected event; 26.4% had adverse events; 18.1% patients were harmed; 52% harmful events preventable, 28.5% not preventable; 19% unclear

The Kennedy Report

Identified shortcomings in

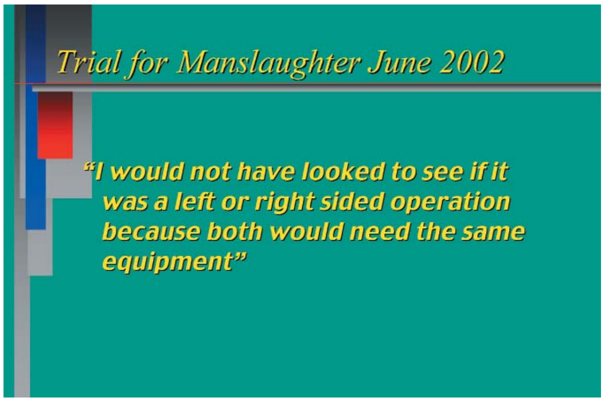
systems
infrastructure
individuals

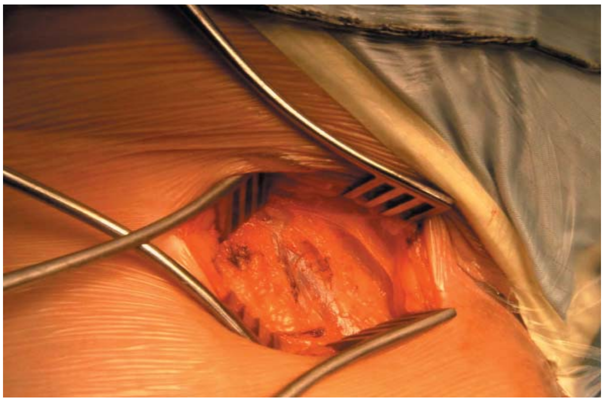
Learning from Bristol

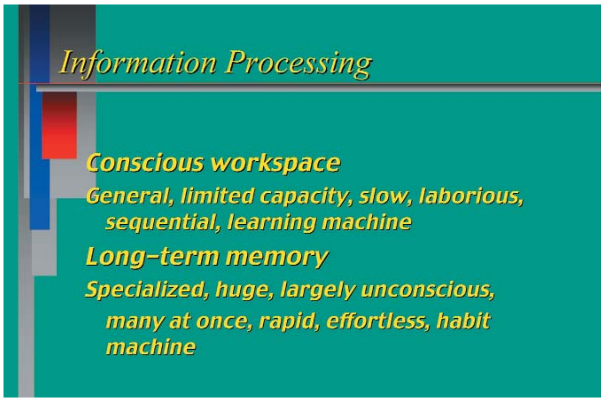
Doing your best is essential but not enough

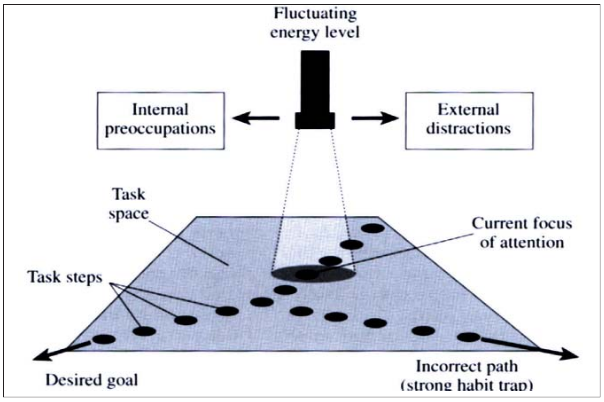
Good performance requires
agreed objectives
effective team
appropriate systems

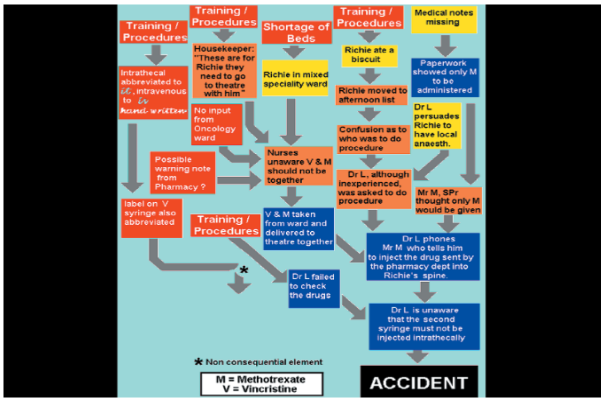

'You're taking out wrong kidney, surgeon was told'
By Clare Kitchen
Goel: Said to have dismissed student's warning
Graham Reeves: Died five weeks later
John Roberts: In charge of surgery
PAY NOTHING FOR 6 MONTHS
If you can find a higher spec laptop for £999 - buy it!


Trial for Manslaughter June 2002
"I would not have looked to see if it was a left or right sided operation because both would need the same equipment"




Information Processing
Conscious workspace
General, limited capacity, slow, laborious, sequential, learning machine
Long-term memory
Specialized, huge, largely unconscious, many at once, rapid, effortless, habit machine


Fluctuating energy level
Internal preoccupations
External distractions
Task space
Current focus of attention
Task steps
Desired goal
Incorrect path (strong habit trap)


Training / Procedures
Training / Procedures
Shortage of Beds
Training / Procedures
Medical notes missing
Intrathecal abbreviated to it, intravenous to iv hand-written
Housekeeper: "These are for Richie they need to go to theatre with him"
Richie in mixed speciality ward
Richie ate a biscuit
Paperwork showed only M to be administered
Richie moved to afternoon list
No input from Oncology ward
Dr L persuades Richie to have local anaesth.
Confusion as to who was to do procedure
Possible warning note from Pharmacy ?
Nurses unaware V & M should not be together
Dr L, although inexperienced, was asked to do procedure
Mr M, SPr thought only M would be given
label on V syringe also abbreviated
Training / Procedures
V & M taken from ward and delivered to theatre together
Dr L phones Mr M who tells him to inject the drug sent by the pharmacy dept into Richie's spine.
Dr L failed to check the drugs
Dr L is unaware that the second syringe must not be injected intrathecally
* Non consequential element
M = Methotrexate
V = Vincristine
ACCIDENT

Behavioural Markers of Surgical Excellence

- 166 arterial switch operations
- 16 cardiac surgeons
- Procedural excellence scores.
- Outcome indices:–
  - 1 death
  - 2 death and/or near miss.

Scores were consistent across both indices

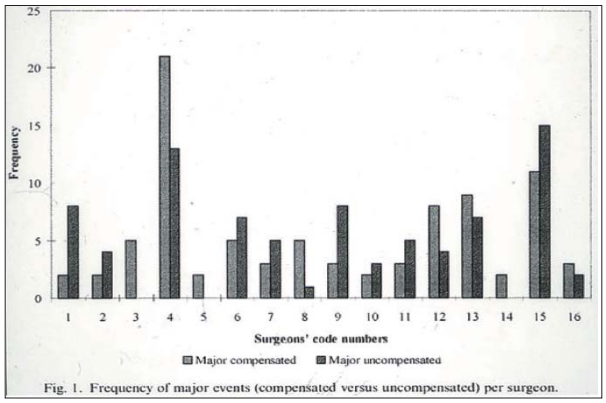


Fig. 1. Frequency of major events (compensated versus uncompensated) per surgeon.

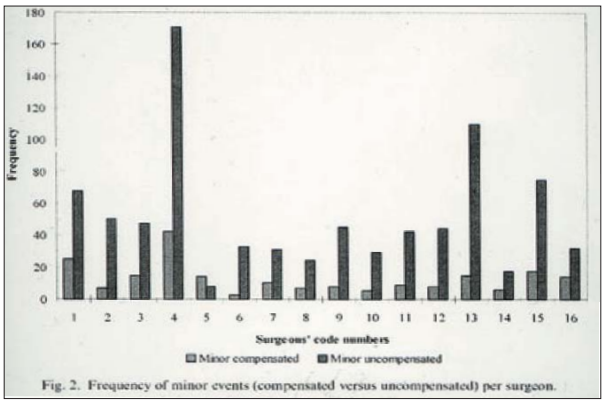


Fig. 2. Frequency of minor events (compensated versus uncompensated) per surgeon.

Good outcome is associated with:–

few or no uncompensated major events
less than ? 6 uncompensated minor events

Carthey J et al. Safety Science May 2002

Team working & Performance in the NHS

- Patient mortality is related to team effectiveness
- NHS staff think they work in teams
- Less than half work in effective teams shown by productivity gains and service benefits
- Dysfunctional teams are common, self orientated and inert
- Successful remediation is unlikely without

The Work of the NCAA

- A Special Health Authority
- Assessment of doctors whose performance is called into question
- Support for employers
- Support for and remediation of doctors where appropriate

Assessment concerns

27% clinical capability alone
29% behaviour alone
65% behaviour and other concerns

The best surgeons can anticipate potential pitfalls better than their colleagues.

Dominguez 1998

Trust and Judgement

Trust

An essential component of practice and consensual government but said to be in decline

No longer seen as sufficient in complex systems

Increasingly replaced by

- a culture of suspicion
- increased desire for a guarantee

But

- Ultimately we have to trust the guarantee!
- Trust like morale is domain specific
- Look at what we do not what is said

The Question of Trust

- Transparency
- Opacity
- Betrayal

The opacity of transparency.....

the real problem is secrecy

Intelligent Accountability and Professionalism

Onora O'Neill, 2004

"The last temptation is the greatest treason

To do the right deed for the wrong reason"

TS Elliot. Murder in the Cathedral

Functional outcome after open AAA.

Williamson et al, J Vasc Surg 33: 913–20; 2001

154 patients, mortality 4%

Operative mortality 4%

33% had reduced functional activity long term

18% would not undergo operation again

Regulation and Licensing

Medical Practice I

- 1858 The Medical Act
- 1946 The NHS Act
- 1960 GMC: Advice not to criticize colleagues

Medical Practice II

- 1998 GMC Determination on Bristol
- 1998 Senate's Response. RRTs
- 1998 Good Medical Practice
- 1999 C Es Responsibility for Clinical Practice
- 2000 Team working in Surgical Practice
- 2001 The Kennedy Report
- 2002 NCAA

Regulation

- GMC overseen by
- CRHP (oversees nine professional bodies)
- Royal Colleges overseen by
- PMETB

Achievements and Challenges

Achievements

- Largest most equitable healthcare system
- Relief of pain and fear
- Advances in knowledge beyond individual benefit
- Setting stage for further advances

Challenges

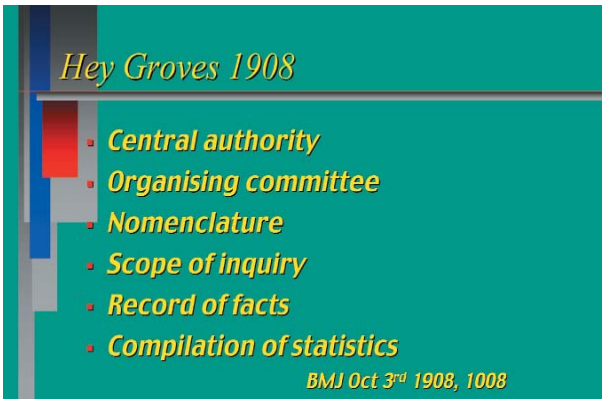
- Improving safety, effectiveness and appropriateness
- Improving training and assessment
- Embedding multi disciplinary team working
- Resolving political : professional dissonance

Political : Professional Dissonance

- Political imperative to publish results of individual cardiac surgeons by April 2004
- Professional requirement to publish results for individual cardiac surgical teams

Hey Groves 1908

- Gastrectomy 44%
- Resection of rectum 24%
- Prostatectomy 23.5%
- Appendicectomy 9%


Hey Groves 1908
Central authority
Organising committee
Nomenclature
Scope of inquiry
Record of facts
Compilation of statistics
BMJ Oct 3rd 1908, 1008

Process Industries Safety Management (PRISM)

Views on experience sharing

Mr Lee Alford
Operations Manager, European Process Safety Centre

Good morning, ladies and gentlemen. I will take a very quick review of a thematic network on the subject of human factors in the process industries. This has just finished its EC funding and is entering a second stage.

I belong to an organisation called the European Process Safety Centre, who are subscribed to by industry to develop and promote best practice in major accident safety. In 2000, we agreed to co-ordinate this project which comprises about 45 participants across Europe, predominantly in the industrial sector, chemical and process industries.

Human factors
I should like to remind the audience what 'human factors' is. It has a health component, as has just been described by Tony, and it also has a safety component. EPSC is very interested in the human factor side, as far as major accident probability is concerned, but we can also say that, during PRISM, we also drifted into looking at personal injury frequency and, on to issues such as stress and the direct effects on health.

PRISM
Human factors is a very broad, catch-all topic. I am not so sure that I like the term human factors, because it is often more confusing than it is illuminating. It is often better to break it down into bite-sized topics. We divided PRISM up into four topic themes:

- Focus Group 1 was on organisation and cultural factors. This was led by two small consultancy practices based in the UK and it covered such topic areas as safety culture, team working and behaviour-based safety.
- Focus Group 2 was studying human factors and normal operation, as I would say, in the chemical and process sector. That included topics such as training and procedures, task design, human machine interface, and human computer interface.
- Focus Group 3 studied human factors in emergencies, which you could consider as a subset of the normal operation. We were looking at control room layout, the implications for alarms and over-alarming, and alarm flooding. We also had a group looking at the use of virtual reality. This group was looking at this tool and its potential, as far as studying human factors issues as was concerned.
- Focus Group 4 covered engineering design. This particular group were very interested in the hard issues concerning human factors. They were studying topics ranging from maintenance and maintenance error, right the way through to correct signage on chemical plants.

A voice from the past
For my sins, I have studied management and management thinking in a previous life. I pull out this slide simply because a US researcher in the early 60s, Robert Blauner, did a milestone research study on alienation and freedom. He studied four industries, including the chemical and process industry. He studied car assembly workers, textile workers and printing workers. He looked at the work in four dimensions which, rather negatively, were powerlessness, meaninglessness, isolation and self-estrangement. He concluded – and this is quite interesting for me, as someone who has come out of the process sector – that in fact chemical process workers (and this is in the early 60s),

> *"operate prosperous, technically advanced plants, where manual work has been automated. They control their work pace, have freedom of movement, social contact and teamwork. They develop an understanding of the chemical reactions which they monitor and also develop a sense of belonging, achievement and responsibility. In addition, they have close contact with modern, educated management."*

Estimated number of 'human errors'
However, rather than be complacent now, let me show you this graph which was taken from a Scandinavian study that was looking at various sectors, including the chemical and process sector. There is no doubt that, as plants have become more reliable and safety management systems have been installed, that there is an increasing attribution of human error to accidents, quite inevitably. This slide takes pains to state that it is actually attribution, so that it is investigators after an incident has occurred, who have put what is perhaps not explainable down to human factors. This could well be discussed throughout the next few hours, as to whether this graph really shows a true picture. There is no doubt that the attribution of human error is on the increase for accidents but, in fact, there may be a difference here between subjectivity and objectivity, and also the definitions of human factors and human error.

Role of regulation
Looking ahead to some of the break-out groups, I would like to show this slide, which was presented at one of the meetings I attended under the auspices of PRISM. There was a director there from Norsk Hydro in Norway, a company that has an excellent health and safety record, but he was bemoaning the fact that most of the incidents within Norsk Hydro are caused by behaviour, but they react with technical solutions. He was talking to an audience composed predominantly of the regulatory authorities, so he almost seemed to be saying, 'We would like you to save us from ourselves, because we tend to react with technical solutions when, in fact, we should be reacting with behaviour solutions.' It was almost as though he was saying, 'You are co-conspirators in this, in that you are encouraging us to put in technical solutions to incidents that have behaviour solutions.'

Organisational learning
I would also like to illustrate a topic you could ascribe to organisational learning. This was provided by a company in the North West of England, who had undertaken quite intensive behaviour-based safety programmes. They had really empowered the work-force and encouraged a can-do mentality. The engineers and the operators set about trying to make the plant ergonomically sound. They decided to fit a handle on a man-lid on a vessel containing pentane which entirely compromised the seal integrity of the vessel. In other words, they bypassed their entire management of change process and systems. As a result of this little exercise, in trying to improve matters, we can also introduce some other unforeseen consequences of our actions – we can forget the big picture and introduce further errors.

PRISM
PRISM, the network, finished its funding in August 2004 but is to continue under the auspices of the European Process Safety Centre. We have maintained a website since 2000, where we have published a huge amount of resource. We have 450 registered users as of today and we are also starting a Human Factors Working Party within the European Process Safety Centre. We will be publishing a book on PRISM and, as a result of our contacts, we believe that we have a viable conference to be held in 2006.

We have also spun off a major European-funded project on the use of virtual reality, called VIRTHUALIS, and I will speak a little more about that.
Training: role of simulators

VIRTHUALIS is a project whose objective is to exploit virtual reality for producing a new technology, to cope with human factors issues across all areas of the process lifecycle, from design right through to decommissioning. That will start in January 2005.

Networks
Some of my own experience of operating and administrating European-funded networks is that live meetings are still essential. I do not believe that virtual networks – solely virtual networks – work, from my own experience of operating the PRISM website. We had very disappointing results with some of the discussion groups that we installed onto the website, and we had very few people who elected to upload materials onto the website. We therefore need to use technology within networks with care.

The web is passive and we always find excuses not to visit websites and not to participate in virtual conferences. Emails are active, and we have used emails from the website, but they are highly ignorable and so they have to be made as eye-catching as possible. Net meetings have potential for developing materials within the team and for team writing. We have used net meetings very sparingly, but there is potential there. They are extremely good for surveys and, without doubt, you can get an extremely good response on very specific questions by using surveys on the web.

Human centred design
How about the future? The objective of PRISM was to identify future funding priorities. One of the major topics to emerge from PRISM is the management of change, as illustrated by this slide, and especially organisational change. Safety professionals and the safety community are very worried about organisational change and its impacts on major accidents. They do not have the tools to deal with them.

Emergency preparedness
A second stream is emergency preparedness. A key question here is, do personnel practice often enough to remain competent in dealing with emergencies? That particular question needs to be answered in normal operation. We also have a topic here of normal situation management, where it has been found that there have been plenty of chances to recover major accidents, but they have not been taken. There are a number of reasons for this, one being that operators go into a 'flight or fight' response and they do not look at the bigger picture. They suffer from 'cognitive lock-up'.

Another emerging topic, coming out of emergency preparedness, is crisis management. What happens and what are the human factors issues related to crisis management, once the accident has actually happened? Believe it or not, when an accident has happened, it is more probable that other accidents can happen.

Thank you very much.

PRISM: EU Network on Human Factors in the Process Industries

Human Factors

Mental health

Musculo-skeletal disorders

Direct effects on health

Personal injury frequency

Major accident probability

Human Reliability

Dysfunctional culture

Unclear procedures

Poor interface design

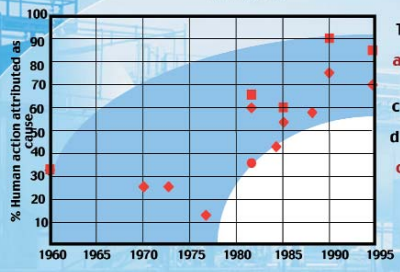
Interaction between people, their organisation, and physical and psychological factors in their work

PRISM

A Voice from the Past

- Robert Blauner , Alienation & Freedom 1964
- Studied worker alienation in several industries
- "Advanced technology like chemicals processing would eliminate worker alienation"

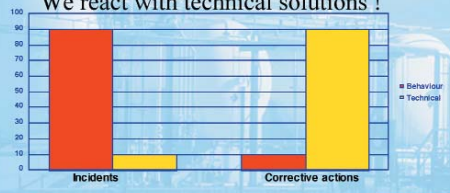
Estimated number of "human errors"



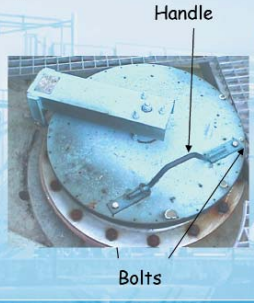
The diagram shows the attribution of "human errors" as causes, which may be different from the contribution of "human errors" to incidents / accidents.

Role of Regulation

Incidents are caused by our behaviour
We react with technical solutions !



Organisational Learning

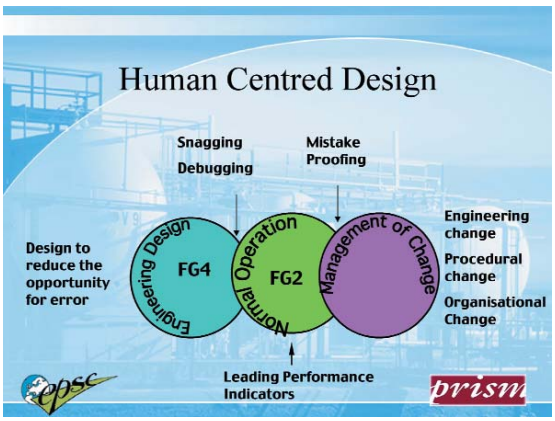


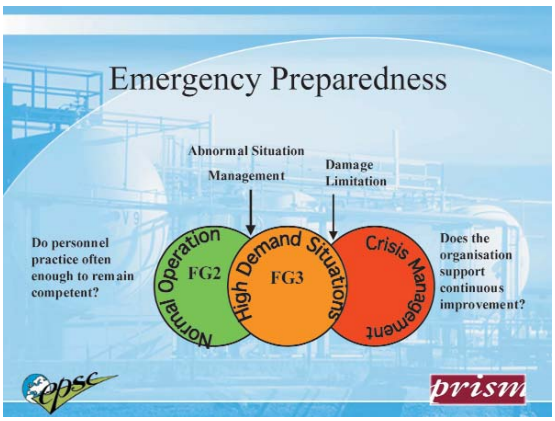
PRISM

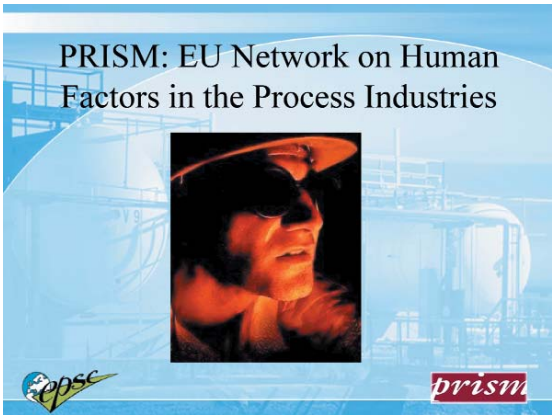
- Finished its funding in August 2004 but to continue under auspices of EPSC
  - Website to be maintained – now 450 registered users
  - An EPSC Human Factors Working Party
  - A PRISM book
  - A HF Conference in 2006
  - Also spun off VIRTHUALIS


Training: Role of simulators
•VIRTHUALIS
To exploit VR for producing a new technology that enable to cope with Human Factors issues in all areas of the process lifecycle.
SAFETY Production
epsc
prism


Networks
• Live meetings essential
• Use technology with care
– Web passive
– Email active but highly ignorable
– Net meetings – potential for developing materials within a team
– Good for surveys
epsc
prism


Human Centred Design
Snagging
Debugging
Mistake Proofing
Design to reduce the opportunity for error
Engineering Design
FG4
Operation
Normal
FG2
Management of Change
Engineering change
Procedural change
Organisational Change
Leading Performance Indicators
epsc
prism


Emergency Preparedness
Abnormal Situation Management
Damage Limitation
Do personnel practice often enough to remain competent?
Operation
Normal
FG2
High Demand Situations
FG3
Crisis Management
Does the organisation support continuous improvement?
epsc
prism


PRISM: EU Network on Human Factors in the Process Industries
epsc
prism

Questions & Answers

John Turnbull: When we break out into our smaller groups, I will ask Tony and Lee to act as a floating resource so that, at your request, they could be called into your group if you think they may have some useful input for you. Before that, are there any questions?

Speaker: I am not sure whether this is a question or a comment. Much of the discussion so far has been about avoiding human error, but there has not been any focus on the fact that humans can be very beneficial. They can contribute to performance improvement and also prevent accidents.

Lee Alford: I agree with you. We do not tend to recognise humans in what I might call their superhuman aspects, where they are far better than machines. Operators – human beings – have possibly saved hundreds and thousands of incidents, as a result of their own ingenuity, but these are not publicised. I would like to hear more stories about heroes who have saved the day at the 11th hour, because that would be very encouraging. We tend to try to design human beings out of systems, unthinkingly, and it would redress the balance if we were to hear more stories about our normal, everyday hero, who saved the day.

Tony Giddings: There are two important aspects in your question. The first is, yes, the human being is actually a pretty good piece of kit, and it can do things which, at the moment, we do not have systems to do.

Let me give you a good example. We have strained every nerve in medical assessment, to try to produce systems to assess the performance of medical students and doctors on competency-based grids which were validated to the extent that they would withstand legal challenge from people who had no insight, no talent, and no appetite for doing something else.

The result of this has been to produce an enormous burden – financial, professional and emotional – for the whole profession, in order to come to a decision about whether someone is fit for the purpose and safe to deal with other human beings' interests. When we have tested the results of this sweated solution against the opinion of experienced and responsible professionals, on the basis of whether a person is OK, we find that we achieve just as good a result from the intuitive assessment of an experienced observer who works with a person for a little while, as from the most complex and detailed methodological system. That is the first point that we should remember: the human being is OK and, as long as possible, we should go on dealing with them – they have many social advantages over the quality-assured systems that we have as alternatives.

The second point is that there are things that we are pretty good at recognising, as humans, which machines cannot do, in the behavioural area. For example – and we will perhaps refer to this later today – you ask us, well, what should we do about this problem of embedded failure in a system, where we have dysfunctional team or a psychopathic individual who is waiting to cause a lot of trouble, but who we know may practice for 20 years without being identified? The answer is that they are identified, because everyone with any commonsense can recognise them by their particular behavioural markers.

What we have lacked in the past is the evidence which will say, 'Actually, if you do that, and if that is the way you think and behave, then there is a pretty good chance that you will not be a safe doctor or surgeon, or pilot or engineer.' We are now accumulating that evidence through a number of efforts, such as the National Clinical Assessment Authority,

which I hope will lead us down that avenue which was earlier referred to, by asking how we stop something happening, which will have such fierce consequences.

Much of this will come out in the medical field, as a result of the deliberations of Dame Janet Smith, the Shipman review, the Ayling inquiry and so on. We used to have these skills but they have been degraded because they were thought to be discriminatory and unscientifically founded, but we should go back a couple of steps and not throw away the human gifts, and which we depend and we need to acknowledge.

John Turnbull: This seems to be the fundamental question. Being in the Royal Academy of Engineering, perhaps someone in the room will correct me if I am wrong, but I was certainly taught – as an engineer – to eliminate people from the system. People are a damned nuisance and cannot really contribute. Perhaps that has changed – I hope it has – but what a disastrous philosophy. One of the fundamental tasks for today is, how do we manage that human component in the system, to make the best of those human skills and talents.

Tony Giddings: Let me just say one thing about that study, because it really is very important. The first thing we have to do is to understand ourselves better, and to recognise – as we have in teaching, for example – that there are different people and different profiles. They learn and they teach in different ways, and they are best at different sorts of jobs. If we could stop regarding the human being as a one-mode issue, and we could relish and enjoy the complexity of our skills, talents and attributes, we would start along that journey which would seek to match the brilliance we have available to us in the human system, with the jobs that need to be done.

Speaker: You made the point about measuring the surgeon's performance as against the team's performance. You said, essentially, that measuring the surgeon's performance is the wrong way and that you should be looking at the team – implying that, in this human factors business, we are looking at the team as a safeguard. You can tolerate mistakes with individuals, provided you have others around who can pick up on those mistakes. Could you comment on that?

Tony Giddings: Perhaps I did not make that quite clear, in the speed of the presentation. It is important that things which, uniquely, are done by the surgeon – like tying knots adeptly, which was the example I used – should be done extremely well by that one individual, who is the only one involved in that process. However, the limiting factors for their performance, given an adequate level of performance in their individual tasks, remain the interactive processes within the team. You need both.

The study from GOS, which was a very important landmark study, indicated this by analysing the individual, and analysing the team, and also analysing the processes that the organisation had put in place. You have three dimensions, all of which contribute to the safety agenda.

We say that the team is important, and there is the point that you make about the other members of the team – the experienced scrub nurse will say to the surgeon, 'Are you sure that is the right anatomy? It does not look quite right to me, but I do not know why. There is something wrong with this. Can we stop doing this, and can you explain to me what you are doing?' That is intuition. All of that is very important team "safeguardianship," but the it does not give the surgeon's individual responsibility any excuse – we have to get our individual contributions right. We then rely on the team as a secondary barrier when, for human frailty, we do not do as well as we might.

John Turnbull: In your break out discussions, I would like you to consider the team as a safeguard as one issue. Another question I would pose is that modern technology actually makes it impossible for the individual to operate solo. While 150 years ago, the surgeon was just

one guy, because of the complexity the surgeon is now totally dependent on a team. The technology demands that he can relate to the team, because he needs the anaesthetist and all the others. A characteristic of modern technology is that it removes the prima donna role.

Speaker: Just a last thought. Is there a problem either in getting good information, or in dealing with problems of the blame culture? How do we get over the blame culture? How do we liberate people?

Tony Giddings: For all of us, this is a hugely important area in society. As I tried to hint in the presentation, it is that ultimately which underpins the demand for guarantees, regulation and things of that sort. It is actually seeking to apply a desirable solution, but one which has many methodological flaws in itself.

Regrettably, we are vulnerable human beings. We are all King Lears and Antigones in the operating theatre. Getting people to accept their own limitations, in the short-term encouraging in them to know when to call for help, or when to stop, think and reassess, is a huge problem. This is partly because of what you referred to which is that, when people get into a crisis, they get 'cognitive lock-out' sometimes. However, others can recognise that.

How we manage to preserve this delicate balance which is not, if you like, totally no-blame – because some people almost voluntarily breach protocols and screw up. And, if you want to have a firing squad in the car park at every hospital, provided it is judiciously used, there may be a point to it! However, we need a just culture, which will enable people to say, 'I did screw up, and I would like my colleagues know about that, because I did not see it coming and I think we should all learn from that experience'. Health professionals are an expensive resource, and if they can be rehabilitated, and without the stigma that this was a Shipmanesque episode, we shall all be the better.

Speaker: I have another question about blame, which is part of the automation issue. It is largely to do with the data that we collect about the accident. Boeing keep a website about whole-loss accidents and about 70% every year of major aircraft loss is attributed to human error. They have collected those data for years back, to try to discover what was really the problem. But a lot of incident and accident reporting is to do with putting the blame on humans – it is this blame culture issue. But it is about collecting good quality data and making sense of the situation from the good quality data, which is the key to quality and performance improvement.

Lee Alford: At the same time, you need to counter that. It all depends where your perception is at the moment and sometimes 'blame culture' is an over-used term, in that a blame culture taken to its extreme is then a 'no responsibility' culture. I have seen this operate in a few organisations for which I have worked. We have to temper this and be completely open, honest and transparent, and say that there are occasions when human beings do screw up, and that is absolutely catastrophic. There is no getting away from that.

Speaker: It is not if you screw up, but when you screw up. Accidents happen, so you look for mistakes. But clearly, the technology does have a role to play. It has to be designed to accommodate people and their behavioural characteristics.

John Turnbull: As I have understood that, you are saying that we should design systems which help people not to screw up. Today is about learning how to do that!

Let us move on to the break-out sessions now.

Plenary session

Feedback from break-out groups

John Turnbull: In the time remaining, we would like to hear feedback from each of the groups. After each presentation we will take points of clarification and query but we will reserve wide discussion until after we have heard them all. The open forum will give us the chance to open up the meeting more widely, both in terms of feedback, and the question about where we go from here.

These proceedings are being recorded, so when making your contributions, please wait for a microphone, and tell us who you are and where you have come from. Your comments will not be attributed, so feel free. The purpose of the recording is so that we have a good record and we may wish to come back to you later with some of the points you make. It can be very easy, in the heat of a discussion, to think that you have understood a point, when actually you have not.

We will start with the technical groups. There were two groups looking at automation and one looking at fault tolerance or fault tolerance systems. We will start with Group 1A.

Group 1A

Impact of automation

Andrew Leggatt: Our group discussed issues related to automation. We were tasked with discussing whether there is a value between us, thinking about cross-industry, best practice exchange? Is this already going on? And then what mechanisms of exchange are there? What would be the way forward, to engender this more appropriately.

In the process of doing this, we decided that we were given 50 questions about automation, which my colleague, Liz Carver, handed to us, and we talked about those over lunch. That provided us with a great opportunity to talk about all the things on this flip chart. The upshot was that we were stuck on the point of definition of automation and so, like good people discussing a topic, we asked, 'What do you actually mean by automation?'

There were several inputs into that. One was that it has to be to do with technology – something had to be done manually beforehand, but now it is not. There were other quite decisive things, such as that there had to be a decision in there. We ruled that out because we did not have to have a decision for automation, but it was basically taking a series of inputs and producing a different output which was our working definition of automation.

We have there the beginnings of our idea of what automation is. We came up with several issues to do with the paradox of automation. I do not know whether people here are familiar with the paradox of automation but the idea is that you automate things and then, all of a sudden, a whole load of things come out that you were not expecting. These are quite interesting things – the downside of automation were put in the disadvantages or negative impact.

This all makes the big assumption that you have not thought through your whole system engineering design, or system design. Unintended or negative outcomes of automation

are those ones which you had not foreseen coming your way. So at the top of our list we had unintended manning duties - problems. Roger Harvey from QinetiQ said there was a fantastic opportunity – we can de-man tanks. We have four or five guys working on a tank and we can have only three people operating a tank – but the problem is, all of a sudden, you have forgotten about all those other tasks that people in tanks do. They do not just drive along and fire shells and whatever, but they have to go off and investigate, or guard the situation – all of a sudden, there are unintended aspects of their task which were not considered in the automation, and we have a problem.

There are also other things to do with the impact of automation, in reducing the skill of those individuals who were in a highly skilled job, but who now become more of a supervisor, without the skill required. There are all sorts of personnel issues. At this point, it suddenly occurred to me that the MoD – and it is a principal customer – came up with a terrific process called Manprint. It is from the US, but we have named it HFI, and this is a systematic way of managing the introduction of technology, automation or changes to the system. All of a sudden, leaping down here somewhere to enabling factors, we had –

John Harrison: Systematic integration of human factors.

Andrew Leggatt: Automation is fantastic, isn't it! [Laughter] If you have the process to capture your system-bound risk appropriately, it helps a great deal.

We have another issue which was raised by Caroline Horbury from the London Underground – and obviously, none of this is attributable – about poorer mental models. The point that was being made here, which is slightly jokey, is that you have to have a changed mental model of the system. If you have an automated system, you have to understand, as well as the system – for example, the aircraft system, where you have to understand the aerodynamics of the air going over the wings – you can no longer just have that understanding but you also have to have an understanding of the control systems which you are now operating, one step removed. This increases the complexity of the mental model that you have to hold which, at the same time, changes the skills levels required. There is rather a paradox here, providing higher skill levels. To be successful, you will probably need to have better skilled individuals, or at least different skills, to be able to cope with that complexity.

There was some discussion. I am aware that I was in the Royal Academy of Engineering here, and so I have to be careful in what I say, but there was the thought that automation is generally automation of the possible and not necessarily automation of the most sensible. Automating is the easy task. Taking the airline industry, it is very easy to sit asleep, or read the newspaper for six or seven hours with nothing to do, but at the last moment you have a whole load of activities which have not been automated – like filling out the checklist before you get down on the ground.

It is slightly problematic in that it may be the sensible way to manage that automation but, when it comes down to the end operator, they feel that they may have a raw deal from the automated system. Flying straight and level is not actually that hard, although it is a little tiresome, and it is an OK thing to automate, but you have not automated those really difficult things. For example, in some of the aircraft that are available these days, if you have a sudden turbulent situation, you have three or four seconds' warning that you are about to lose autopilot, and you have to grab hold of the controls and you have some very difficult flying to do because it is no longer straight and level.

We then talked about team structures that actually end up being affected by automation. One of the issues we came up with here is that it tends to take away the bottom rung of the ladder. For example, the complements of ships for the MoD, as Roger pointed out, has shrunk more and more and, all of a sudden, the career progression, if you have gone down

a very narrow, automated path, means that it is much more difficult to jump into another area. The personnel issue is a softer one, but it is a very important one which is compounded there and made more difficult.

What could be seen as an unsuccessful automation issue is that the technology is forced on people. It will be a disadvantage if it is forced on you but, if you are a willing consumer for the automation, then you have a much greater chance of success.

Let us talk about the positive side. The reason why we automate, somebody cynically said, is because we can, but there are actually important drivers there. Automation is about trying to make systems more safe, by improving their performance. There is also a cost implication and, in some cases, it is forced – particularly in the defence world, where there are no longer enough people available to do the job. Automation is therefore a requirement of a new system coming.

There are two strands to safety in automation. One is that you can do the task better, but it also removes people from a risk situation. Thus, in the off-shore oil industry, one of the ways of improving safety there is to expose fewer individuals to risk.

That is a summary of some parts of the swot, and I will very briefly answer the exam questions that you so kindly set us. Is there value in us linking best practice between industries? There was an overwhelming yes to that, with no dissenting voice. Is it going on? Maybe – that is the situation. There are situations provided to do it by the various institutions, but they tend to be a little piecemeal in the sense that IChemE does it separately from IEE and so on. There are these separate organisations that are having a go at trying to do this, although they are not necessarily linking across industries as effectively as they could be.

What mechanisms are there for greater exchange? There are things like conferences but, as someone pointed out, the People in Control Conference – a cross industry conference - had to be pulled last year because there was not enough interest.

As to the way forward, I have written down that perhaps this is the route where consultancies really work. Consultancies do dot around industry, and some corporations which go across industries also have the opportunity for cross-industry learning. There were the heady days when BA Systems used to own Rover, and aerospace technology trickled seamlessly into the car industry. [Laughter]
If there is anything you would like to ask, I am open for questions. [No questions]

Group 1B
Software vulnerabilities

Andrew McGettrick: Our group had some problem in knowing what our remit was. We started off as software vulnerabilities, but then perhaps software and automation was part of our discussion, and that was of course related to human factors too. We wandered through that general territory and these are the group's findings.

In terms of software and automation, many of the high profile applications are to do with safety software systems, many of which are terribly complex – so complex that we could not ask users to interact with them without some form of control.

The top left hand box [on flip chart] is to do with advantages and benefits. We felt that one of the great advantages of software was being able to control highly complex systems. Where total automation was not possible, then there is a possibility of an envelope of control, and software again is able to provide as support to make sure that things do not go wrong.

The benefits of software are its perceived flexibility, lack of weight, the ability to build better interfaces, as well as to promote simpler interfaces and so on. There is also increased safety, as was mentioned before.

One of the other advantages of software we saw was that through software systems there is the ability to monitor behaviour and, in some cases to evaluate intention.

The disadvantages or software, or the vulnerabilities, include viruses, security threats and so on. We also saw one of the disadvantages as being the apparent ease with which you can modify software and also the temptation to modify it. We saw that as a disadvantage and as a problem.

There is also the hidden complexity that is associated with software. That hidden complexity is often there in order to achieve simpler interfaces, so that although the interfaces look simpler, what may really lurk behind is increased complexity.

De-skilling was mentioned by the previous group, and we also thought about that as a disadvantage. A member of our group pointed out that de-skilling need not be a disadvantage, however, and that really the proper thought processes are to think clearly about what the role of an individual is in the context of a software system. If you think about the design from that point of view, then you will not end up de-skilling, but re-skilling will happen. This business of thinking about the role of the individual was actually quite important.

Other disadvantages related to the perennial problem of software that comes from elsewhere thus COTS (commercial off-the-shelf products), or SOUP (software of unknown pedigree). It seemed appropriate to think of that over lunch! Often, these exist but were not developed with safety in mind.

One of the developments on the horizon, for coping with these disadvantages, is the concept of autonomic systems. These are a new development, based on the idea of the autonomic nervous system, whereby in the human body things happen without you thinking about them. The human body tries to get rid of viruses and so on, without you thinking about it all the time. There are also developments in the software world, which are trying to do the same sort of thing – there are self-healing systems, self-organising systems, self-optimising systems. These things are all on the horizon and we are looking for some of them to help with some of the disadvantages.

When it came to talking about conditions for success, these included things that could easily be automated – like routine activities, for which there are formal instructions and so on. Something else – and this is an awful thing to say – is that one set of stimuli to development is accidents themselves.

One of the other conditions for success is this notion of team activities, which came out significantly in the medical presentation this morning. People spoke about team activity in the context of a cockpit, where people reinforce one another and so on. We need to thinl carefully about the nature and the role of teams in the context of this.

In terms of barriers to success, complexity is an important one. Lack of proper methodology is also a barrier. We also felt that, in some cases, operators were insufficiently

involved in design. We also saw one of the barriers being how we can achieve some of the reliability levels that we have heard about this morning.

In talking about the transferable ideas, and ideas that came across from some of the other areas, we felt that the idea of a team was quite important, and not just being a collection of individuals, but perhaps a team that is characterised by mutual trust and respect between individuals. This means having common aims and objectives, and having roles defined. These teams are not just the teams that are in the cockpit but they are also the teams that are involved in design and so on. We felt there was quite an issue there, with respect to teams and to teamwork.

We also felt that the notion of trust was increasingly important. Trust crops up now in the context of software: do you trust the software? But it is also about trusting individuals and systems and so on. We felt that this concept of trust is one to which we should give greater attention.

We must have ideas that are transferable around the area of interface design. We did not really have the expertise to identify all of this, but we felt there had to be transferable ideas in the process industry, in air traffic control, in the schematics of rail networks, of cockpit design and so on. There had to be scope for transfer. Part of this was strategies for alarm design, for making sure that you did not get floods of alarms – identifying high priority alarms, and so on. There was a lot in this.

Lastly, we were worried about this concept of risk. We just wanted to make the observation that, taking into account recent events and so on, increasingly, we should be taking account of folk who were deliberately causing serious hazards. Thank you.

John Turnbull: I have one question for Andrew. You mentioned, on the plus side of software systems, monitoring behaviour. Did you mean the system, or did you mean the controller of the system?

Andrew McGettrick: It was felt that the software could actually monitor what was going on and, in some cases, evaluate the intention and so on. How that information would be used, however, is another matter, but there is scope for software to do that.

John Turnbull: Does anyone in the room have experience of software systems that are actually read afterwards, to check on competent performance, and operator performance?

Andrew Leggatt: There is engine monitoring in aircraft.

Speaker: [Without microphone] ..... there are quite a few like that in transport systems, and you find that the software system is monitoring what is going on and then it is actually used to determine whether or not the person operating it has been operating it correctly. We download the data on train journeys into a database .....

John Turnbull: The other field where I have seen it is in truck fleet management using GPS, and transmitting back to central control where the vehicle is, its speed etc.,.

Speaker: [Without microphone] ...That will have a big impact on the trust issue.

John Turnbull: Thank you. Let us move on to fault tolerance next.

Group 5
Fault tolerance systems

Louis Blache: Our group was tasked with looking at fault tolerance. One of the first questions was, what sort of fault tolerance are we talking about? The key point was whether fault tolerance is related to what happens with what we describe as the engineering part of the system, or the human part of the system. We were considering both of those. A key benefit of fault tolerance systems is that they can help to maintain safety, both in terms of guarding against and dealing with human failure, and also with equipment failure.

If we have fault tolerance systems, that also gives us some space, such that we can reveal errors in a safe environment and people can learn from them. If an error is committed by somebody, the system will reveal that and they can understand from that, and they can understand from that without there being a risk imposed. There is a definite learning advantage there. Also, because those errors are revealed, we can have operator feedback and we can learn again from that, from operator knowledge.

Our third point is that we can get the best, if you like, from the different parts of the system. The fundamental issue we were pursuing was perhaps not what are the differences between industries but what is the basic process that we should bring to bear in this sort of situation? That will ring bells with certain people, who may think of human factors integration plans, for example, but we need some way of bringing engineering knowledge and human factors knowledge together. It is perhaps somewhere where concepts exist and are known but there is that whole issue of the practicalities: are we getting the most of the systems and getting those things done? Even at a regulatory level, we still spend to split out how we deal with human errors, how we deal with engineering errors and how we deal with tolerance. It is a question of bringing those together, and that was seen as very important.

In terms of disadvantage and problems, the first point we had there was sabotage. We reached that by thinking about what levels we were thinking at, but our systems are open to attack – as we know now – from terrorists, from people attempting suicide on level crossings, and so on. Should we, in the context of our systems and in terms of error tolerance, actually be considering these wider factors. These are particularly in people's minds at the moment, particularly perhaps in the rail industry. Once again, that is a question of remit and error tolerance, and whose errors we should be protecting against. Should we be considering violations by our own staff?

There is a disadvantage in terms of the human operating in an error tolerance system. You are potentially removing them from the controlling space, as Andy mentioned, with automation, and so there is a similar issue about how the person sits within that system. How do they get the knowledge and the skills? If they are heavily protected from that, how do they get the knowledge and skills to work with those systems when things break down.

Our final point there is correct specification. Could I ask someone in my group about that?

Speaker: Basically, if people are not specifying what they want the system to do in the first place, or what they want the equipment to do in the first place, they are likely not to get any results. In other words, if it is not specified, it will not happen.

Louis Blache: In terms of enabling factors, obviously error tolerance systems require the management systems and so on to support them, and so there needs to be understanding of the implications for those error tolerance systems. As automation starts, they will change the training requirements, but what are the needs for that? Then they change the

requirements on operator specification, and they will require procedural support. Another issue is feedback: if we are protecting people from errors and so on, how do they get that short-term feedback, if they are working in a system which hides that from them? That is the kind of thing that may be removed if we go to highly error tolerant systems.

What we really want is a global engineering process which brings in knowledge from different industries and different parts of an organisation. There was a good deal of discussion about things being compartmentalised and the need to spread between boundaries. There is the issue that we need a language to do that in – we do not just need the human factors and engineering language, but we need to be able to understand both those languages.

Barriers to success? In creating these protective systems, there is a barrier in terms of understanding of operators, and operators understanding the limitations of the systems and the systems which they work within. Another key issue was system interactions. OK, we have a tolerant fault system, but that system is linked to another system – so air traffic control is linked to pilots flying, and also linked to various other systems such as the European Traffic Flow Management System. These are all systems and we may focus on error tolerance in one, but there are linkages which require error tolerance. Generally, these systems end up with management teams, and that is another area where we need to consider whether these management teams are sitting somewhere in Brussels, controlling the traffic flow across Europe, and do they have error tolerance in what they are doing?

There is also obviously the classic issue of complexity and, as we build error tolerance into the system, we then have back-up systems and the system becomes more complex and more difficult to understand.
That is our summary. Does anyone else in the group have points of clarification? [No]

John Turnbull: I would now like to turn to the more human-related groups, where I am thinking more of training and competence testing, monitoring performance, organisational learning and work patterns.

Group 2
Training & competence testing

Professor Kenneth Hambleton: This is one of the loosely-coupled systems, full of people rather than things. We have used this as an aide mémoire, rather than as a presentation. We were asked to look at training and competence and, cutting to the chase, we had a good cross-section of various sectors, ably assisted by Tony, who gave us some very interesting medical stories. We found that the problems and issues were indeed common across most sectors.

We homed in on two main issues: the problem with procedures and the problem of team training. As one or two of the groups have said, because systems are large and complex these days, they are handled by teams of people and not by individuals. We were rather concerned about how you maximise the training of the team rather than just the training of the individuals.

The strengths are, of course, that the team is – or should be – better than an individual, if it is trained and worked properly. The other procedures are necessary in order that people all sing to the same hymnsheet. The disadvantages are that no single person knows all

about the thing any longer, so that you have to work as a team. There are several disadvantages of procedure. First of all, in my mind at least, procedures can only handle things that can be anticipated. You can only write a procedure for something that you have anticipated and therefore you can write a procedure to find your way through it. However, our problems cannot always be anticipated and therefore, however good this procedure might be, it might not be good enough to handle them. This was a source of worry.

Apart from that – and as some of the examples from this morning showed – although there were good procedures in place, they were not always followed. We have a problem that the procedures themselves may not be adequate or perfect, but we then have a problem that the procedures may not be sufficient to start with and they certainly will not be perfect because you will not have anticipated all the problems that you will ever experience with this system. Then, the people themselves are not perfect. Most of the examples of catastrophes this morning occurred when people were not actually following procedures properly.

The interesting observation there, from around the table, was that most times it does not matter – until it does. Most people cut corners on their procedures and we have talked about dodging red traffic lights, and cyclists weaving round pedestrians and cars in central London, but most times it does not matter – until the cyclist is killed. We are all rather surprised the more cyclists in London are not killed, when not following procedures.

Procedures may not be perfect, and people may not follow them, but that then raises the issue – why do they not follow them? It is because they get away with it, since there are no sanctions applied. So, even when people are observed not to follow procedures, they are not hauled over the coals for not doing so. We then get into the issue that there is a financial implication here, with lots of time, effort and resources, and feedback and sanctions and so on – so there are cost implications. So that was about procedures.

Team training – enabling factors for success: here, we looked upon the team of people involved as a system in itself, and the people themselves are a subsystem – and they have to interact properly with each other for the whole system to work. Once again, Tony gave us some good examples of a surgeon operating on the wrong kidney, but nobody blew the whistle – even though other people may have recognised there was a problem, nobody said much about it. I have therefore tried to identify some of the issues as to why this happened, and it starts off with a silo mentality. Everyone has their blinkers on, in their own part of the system – they are looking internally, looking downwards, and they are not looking upwards and outwards at the bigger picture.

A number of factors apply here. First, there is education. We were all taught special branches of engineering and yet, to make a proper system, you need practically every branch of engineering. The organisation you are in does not help you to cut across these boundaries and interfaces, because the organisational structure does not easily help you to help people in different parts of the organisation.

There are responsibility issues and if you try, somebody will say, 'You keep your nose out of my patch – that is my responsibility.' Then there is status, perhaps: would a junior nurse dare to tell a surgeon that he is doing it wrong? Perhaps, but probably not. Once again, someone mentioned culture, but I am not sure that I understand that. People talk about culture change, but I am not sure that you can change culture. You can change behaviour then, over a period of time, you could argue that there is a culture shift – although you are not changing culture but you are probably changing behaviour.

However, all those issues led to this silo mentality which meant that, perhaps, the team training was not as good as it could be. We talked a little about simulation, which we felt

could certainly be very helpful. Obviously, aircraft landing simulators are probably some of the most realistic simulators that exist. Dr Bill Bardo told us the story of a guy who was landing the aeroplane on a simulator and the trainer threw a wobbly and put a big gust of wind in. The guy managed to recover and land safety on the carrier, and when he got out, he was sweating. In real life, however, simulating surgical operations or simulating battle-field scenarios, you do not quite get the full adrenaline that you might have if it were real. So, simulation can help, but it will not go the whole way, just as procedures can help but will not go the whole way.

Have I missed anything out there, Tony?

Tony Crawford: The only other thing was about monitoring the whole system – to go out and monitor it – for putting mistakes right when they happen, and not letting people continue to make the same mistakes until eventually they have a big one.

Kenneth Hambleton: That is the problem – you can cut procedures most of the time, until it matters.

John Turnbull: Time is going by, and that leads us very nicely into monitoring operator performance.

Group 4
Monitoring operator performance

Roy Burden: We were tasked with looking at the operator's performance. The group in which I participated was very focused on transport and so we had a hard job to escape the familiarity with our topic. That applied to me particularly, hearing that everybody without exception has referred to the aviation business in a way that is a benchmark for their own. I have to hold my hand up and say that I am representing the Civil Aviation Authority here, so forgive me if I am something of a salesman with some of our processes and techniques.

To come to the subject matter here – interesting, we talked about more than this subject, and we had to remind ourselves that we talking about the performance of an individual. However, it became very clear that you could not talk about one of these topics in isolation from the others and in fact, every single presentation that I have heard, has had an element of our own in it. Hopefully, that will be reciprocated from our own now. It was an important observation that you did not need to go into solutions for one little area, but that you need to deal with it much more generically when you deal with a really suitable solution.

We looked at this from the ground floor up. We picked the individual and asked what things affect him or her. We talked about the removal of human intervention from an activity – whatever it might be, the advancement of technology, and the consequences it has on that person. There is lots of emphasis on the design itself being a deliverable commodity here, but we seem to have ignored that, if we want a human person to be involved, we have to identify what his role really is. If we do not identify it, we should not just simply leave him to guess.

I am coming from my own business here. Aircraft of yesteryear were very dependent on interaction: they had a flight engineer and the pilot had to be much more involved in the conduct of the flight than they are nowadays, as we all know. We summarise this by saying that the people who are involved now, instead of being pro-active about

intervention in something, are actually reactive – they are simply there to wait for it all to go wrong.

I recited a story the other day, although I will not tell you who the airline was just in case some of you are flying with them, but they had an event that was as near to having a really big accident as you can imagine. We are all familiar with these computer screens in the flight deck, CRT instruments. During a landing phase, all of them went out in front of the pilot. He has a training regime that is dependent on those systems working, and he does not have a really good plan B. Fortunately, because of the phase of flight, the aircraft was able to land safely, but the CAA has taken a huge amount of interest in this, because the only safeguard was the competence of the pilot. No question, if it had been a fully automated situation, the drivers for the automation had failed and so clearly it was no longer a functioning automated system, and the only thing that saved the day was a Mark 1 human being.

If, in this context, we expect that the person will only observe the failure, then he had better be well armed with a good toolbox for what to do next. This is not just simply about folding his arms and saying 'Oh dear!', as might be permitted in some areas of our industry, because it does not work well in mind. We were therefore very focused about the effect that automation has and the ability to go and measure whether the output from that individual was desirable or not.

This is where my influence came into the frame now, on reporting protocols. For those of you who do not know much about the CAA, we have a very open reporting scheme. We have a law which says that we must report an event, so we have loads of intelligence about performance measures and about how industry is performing. We also have the confidential human reporting scheme, which is a second tier of reporting and does not identify with any carrier, organisation or otherwise, but gives us intelligence about what the community as a whole is feeling. This is down to the performance measure again, because what is the performance measure of something? Someone mentioned earlier about procedures and trying to predict something that we are not absolutely sure will happen. Hopefully, we have enough anecdotal information in our world to make some reasonable determination of what might happen, but we do not have a crystal ball. However, if we can get some other levels of intelligence coming in this route, we will have a success story in it. I will come on to how we deal with that shortly.

We have talked about simulators and there is not question that they aid the environment in which we wish to train. We can simulate many different things and, while I might refer to a simulator being a flight training simulator, simulating things just by example might be sufficient.

We then said that the biggest influence in this was actually not the individual – he could not determine whether it was right to be involved in automation or not – but this part of the equation did have an impact. That is the organisation driver, if you like – what they want to achieve, how they want to achieve it, the training commitments, and the commitment of the organisation to order itself, to deliver safety or whatever. There are phrases there that you would recognise, such as risk management, planning for something, but introducing this openness about inspecting oneself, to ask whether we are doing what we set out to do. There is the chief executive, if you like, scene setting, and somebody in the organisation giving intelligence backwards, to say whether you are actually doing what you set out to do.

Our group leader picked up about the effect that society has. In our world, we all have values about things, and I would say that they probably had the most influence. If we value something being done, we can relate to it far better. In our own world, if we are travelling in aeroplanes, we value the fact that flight crew are valued themselves. They sit

their on the flight deck, with our lives in their hands when we fly. On the other hand, if you go into a restaurant, and the waiter or waitress is not someone we respect greatly – and our society tends not to – then the output we get from that should be expected. We do not have great interaction at that level.

One of our colleagues in the group represented the train sector, and talked about the difference in perception between a train driver and an airline pilot, although they are clearly both delivering a similar safety level. Nevertheless, the perception by the community as a whole is vastly different. I am not sure that I know the answer to that, except for some historical issues about the wonderment of flight, possibly, that we have not yet relinquished.

That is basically a summary of our group's discussion.

John Turnbull: Thank you. Has anyone in this room ever been forced to back off from monitoring the performance of people in a system? Historically, I have been forced to back off from monitoring operator performance by organised labour although, as you can gather, I am somewhat out of date and perhaps things have improved. Is there any recent experience of being forced to back off?

Speaker: [Inaudible] I have been asked to retreat and leaves things alone.

Speaker: [Inaudible] I have seen backing off in a situation where there has been a reluctance to respond to what I consider to be sensible monitoring and a number of the parties complained about the exercise. They eventually got it stopped and closed down. It was a teaching situation.

John Turnbull: I have never quite understood whether the teachers' objections to Ofsted are to do with the principle or the practice. It is probably both.

That leads us rather nicely into organisation learning.

Group 6
Organisational learning

Group Spokesman: **Sandy Grant ....** from lots of different backgrounds. I teach students industrial design and human factors is a part of that. I talk about product semantics, that the products they design should be able to communicate to the people who are going to use them. Perhaps that is done with VCRs and DVD players, and perhaps it will be an easier product to learn to use, and it will be less error prone.

We were putting up our flip chart pages here, and I was wondering how to get this bar off. *[Talking about flip chart]* That blue is very significant, because it is shouting out at me, so it is communicating something to me. But then that is all you have to do, and so it is pretty useless. I have made an error there, and this is a really high risk situation – perhaps I could have died because of that. So that is communication, and design is very important.

We have not followed procedures exactly in filling in the grid, but we have some useful information for you. It is a mixture of summaries, outputs, views and insights – we hope, in some areas – and some models, sketches and diagrams.

Our methodology includes a page of key areas that we have looked at. That will just give us some focus, as we jump between these areas. One was culture, and the subject that we were looking at was organisational learning. So there is culture and we had some thoughts on that. Next, there was reporting and knowledge sharing, which is important, giving that this is organisational learning. Then there is communication, because it does not matter how good you are – you still need to communicate, and there needs to be that communication and support for the communication. Also, since I come from a teaching background, I would like to know how the learning is tested – how do we know what we know, and how do we know that we are doing the right thing? Then there is the role of experience in that.

Turning to culture first of all, we looked at what is culture. We ranged from something which is perhaps fairly concrete, to suggesting that it does not exist at all and that it is a nebulous concept that is actually quite fuzzy. Then, looking beyond that, there are a number of separate components within an organisation, with external pressures and inputs.

There are formal activities which have been devised, in many cases for good reason or in good faith, and there are also informal activities. Some of these informal activities are extremely interesting, and that is something that we looked at. In a sense, the whole is the sum of the parts, and the parts obviously have to have links as well.

I am now in the situation where I am looking at some of the words on the flip chart, thinking that I know what the word is but I cannot remember why we wrote it down. This is how we approached it, in terms of here we have the key elements, here we started off with culture, and we looked at various aspects to do with that. For example, culture will consist of values, beliefs and methods within that culture, and obviously these values and beliefs have to be identified in detail as well, and they would have to change over time.

Behaviour benchmarking is an important aspect as well – how do you state the objectives that you are trying to achieve?

Elizabeth Carver: It is probably worth mentioning that we had a very good spread of different organisations. Several people mentioned the kind of tools that are available, so I hope we can share information about how you might want to assess what your cultural climate is. That might be a useful option. That is what this thing down here [on flip] chart was – it was a framework for looking at that climate, communication, co-operation, competency and consultation.

Group Spokesman: As to inhibitors to change, possibly some people will have experience of this in varying degrees, and it is a big subject in its own right. An important aspect that we have here is honesty – and the more honest you are – to satisfy our concern with this search for the truth. We know the truth when it is there in front of us, perhaps, but honesty is important and how you encourage that. In some of the sectors of the business, there is a log to report incidents, which is one way of doing it.

You may be in possession of the facts but hen there is also the fear of failing and the fear of getting it wrong, and then the ensuing witch-hunt which can identify or follow on from that. That is something that still exists, because we are only human – anything can happen, but we need to deal with it.

[New flip chart]

Organisations – from whom they learn, if they investigate, and are prepared to learn. In any organisation, that will involve the ?....[Difficult to hear – paper on flip chart rustling]

An incident was described by one of our team members, which I will summarise – and I am sure that Jason will help me out here. Air traffic controller had recently come on to the shift, sat down and was about to get on with the job. The end result of this was that there was an incident, although I cannot remember what the consequences were, and there was an investigation which said what had happened: that the air traffic controller did not do this, end of story. They should have done it, and that was it. The wider picture, the wider context, was that not long after he had come in and sat down, two people were yapping in his ear, distracting him; there was equipment that should have been new, but which was not there; and there were two or three other incidents that had just happened before, or which were just about to happen, that he was aware of. So investigation has to be wide-ranging. It is sometimes easier to look for the simple answer and, once you think you have it, then that is it – that is what happened, but in actual fact there are many other root causes. We identified this idea of looking for the root cause.

This scribbly diagram on the flip chart shows the air traffic controller. It is rather like a tree, if you would like to use that as a metaphor. This part is below ground, and there are all sorts of other root causes that are happening. In this case, there was the distracting influence of two people trying to tell the air traffic controller information at the wrong time. They should not have been doing this and they were not following procedure. This diagram has roots like those of a tree, showing aspects that need to be incorporated into any investigation, if the learning is to be good quality learning. It is never only one person but there is a connection, a link – seek, and ye shall find.

That was partly another concept that we covered, which is the maturity of the organisation. How prepared is it to own up to being, to a degree, competent? How prepared is it to take on board this process of learning? That is a measure of the maturity of the company.

Elizabeth Carver: Just to say another thing about the maturity, this is an embryonic conclusion but it seemed as though, if you were not so mature in an organisation like this, you would be looking above here [on flip chart] but, the more mature you were, the further you would dig down, to get to the truth. Perhaps that is another angle in looking at how you analyse what has happened, and what emphasis you put on the degree of effort that you put into finding out what the problem was.

Group Spokesman: [New flip chart] We worked very much on a link, and I guess all the groups do. There is something you say that points towards a conclusion, or something that triggers something else. That is what makes this very fruitful.

In teaching and learning, you have probably heard of the concept of 'believes facts only', which takes the very early student from being able to recite the facts and figures about a subject that is being taught, without really understanding or having any knowledge of about being able to apply them - a parrot can do that - up to a full mastery of the subject, where they can create new insight. So where could we place various industries on this scale or ladder – not necessarily going from basic knowledge, although that could perhaps be a part of it - some industries clearly have a more developed approach to this, perhaps a more mature approach, than others. That is a sense that might be driven by the situation where, say, one doctor is operating on one patient. If there is a human error, then one patient dies. In the aircraft industry, with a pilot or an air traffic controller, if one person makes an error then 300 people die, as in the example from this morning. So perhaps that is a driver to air traffic and the airway industry having such a remarkable safety record, compared with others.

Elizabeth Carver: [New flip chart] These are not prioritised because, in our discussion with some questions, we generated many more questions and I have just tried to capture some of the headlines that people mentioned. One of them was how you demonstrate the benefit of this

activity itself, which relates to this one, about how you build the case to have enough resources to close this loop between gathering the data, doing some analysis and then doing something about it, so that you have this completely cyclical approach. Those two are related.

We asked again and again, what are the mechanisms to share both vertically in an organisation from the top to the bottom and horizontally, both within teams and from one group of one discipline, to another group of another discipline, or from one part of the organisation to another part of it? There are significant barriers in getting people to accept that, if something happened here, it may happen to you. The attitude can be, 'It will not happen to us, because we are OK', or 'It is different for us.' There are all those sorts of perceptions, so that is another significant challenge.

How do we tackle the issues and not just the statistics? This relates back to the issue of maturity. If you are gathering stuff at the top level just for statistical purposes, you will not get to the truth. You therefore have to get to the true issues and the reality, rather than just concentrating on the statistics but, once again, that takes resources - and having enough resources to tackle the problem is a significant issue.

The last point here, which relates very much to the group that was looking at simulation and training, is how we can expose people to risk in order to learn about the real thing? We had discussions about different perceptions of risk in different organisations and in different parts of the country, and how you can try to instil in people that something is a real risk to them – not to the bloke next door but to them as an individual. So it is the degree of responsibility, with regard to the perception of the risk at a personal level.

Those are the points we came up with. In conclusion, we had a very good discussion, and we had organisations at different stages in this whole organisational learning process. There are different things that can be shown and I hope we have drawn some linkages and that perhaps we could follow this up outside the meeting and get some further discussions going.

Group Spokesman: The sharing aspect, and communicating across a wide variety of different schemes and interests is very important.

John Turnbull: Is there anyone in the room who belongs to an organisation which has actually measured the amount of resource, or the proportion of its resource, that it puts into learning or training people?

Elizabeth Carver: There probably would be some numbers. One further point I was going to throw in on that level is that we talked about the time it took to get from a standing start to somewhere where you thought you were achieving some benefit. That was quite interesting, and it was something for years for the process. This is not something that happens overnight – there is a time lapse and we need to take that on board in terms of building the case. This is a long-term and ongoing challenge. The aerospace industry has been doing it for even longer, which is why they are more mature – but it does take time.

John Turnbull: Just to be clear in my head, I can write down here that nobody here knows how much resource they put into training their people.

Speaker: In many organisations, organisational learning would get lost within the training budget, and therefore you would not know how much was going into organisational learning from experience rather than the ongoing process of training.

Elizabeth Carver: The other point is, what is the benefit? The benefit will not necessarily be felt tomorrow but it might be three weeks or three years hence. It is rather like all the arguments for the

knowledge sharing type things. What is it? It is not something that we will actually measure directly, but we will measure it by secondary process.

Spokesman: There is a short-term benefit and longer-term benefit.

John Turnbull: I was careless, I am sorry, and my language was not precise. We are clear about training but the ongoing process of sitting people down and learning from the ongoing experience does have a cost.

?Bill: Our basic knowledge of .... system .... *[Without microphone – barely audible]* .... irrelevant, costs about £1.5 million a year. That is a .... and consequences and pull it all together, and turn it into something that ..... knowledge.

John Turnbull: That is gathering the data. Presumably, the real expense is in people building on that and feeding it back into their structures.

Bill: We have a sort of .... ?conceit, that we gather information without intelligence. The information to knowledge bit is about £1.5 million a year and then, after that, it is difficult to tell because you are putting intelligence back out. Whether it sticks with people is another issue, so you cannot be quite certain how much benefit you are getting.

John Turnbull: The final piece of this jigsaw on people and learning and working is what we either call work patterns or rhythms. Technology has changed work patterns enormously – at least through my generation. What does it all mean?

Group 7
Work patterns

Michael Neale: Group 7 was charged with looking at work patterns and in fact we started off by asking ourselves what that meant.

In our group there were five of us – two from construction, one from aviation, one from process engineering and one from mechanical engineering – so we had a pretty wide spread. We started initially talking about working hours, shift patterns and the like, but we very quickly came down to teamworking, very much looking at work patterns rather than work rhythms. One of the disadvantages of speaking last is that most of the conclusions we reached have already been touched on by one or other of the groups.

We started off by agreeing that teamworking was essentially extremely important and that there were great strengths in having an established team of people who were used to working with one another. Then we quickly thought that that was necessarily the case because, even though a team may have been working together for some considerable period of time, it may be a completely dysfunctional team. There may be bullying with it and therefore it may not be terribly effective.

We also heard from our colleague from the aviation industry that in fact the airlines have taken a completely contrary view. They have decided that flight crews should not be established teams and that there was danger in that, from over-familiarity, so that they would not check one another. Therefore, as part of that organisation, teams are intentionally mixed.

Coming from construction, if I were to assess the competence of a contractor or a subcontractor who was working for me, I would be much more impressed with a team that had been working together for five years, than with five complete strangers who were offered to me. There is thus an obvious conflict there, and an interesting one.

We were then introduced to the concept of team resource management, or crew resource management, which is not a term I have heard – although, once the concept was explained to me, it all sounded very familiar. As I understand it – and, team members, please correct me if I am wrong – it is the ability of the team members to challenge the working practices and, in particular, the ability of the team leader to accept comments from his subordinates.

In the airline industry, pilots in the past would have been seen as the god, and flight attendants would never think of challenging one. Now, however, the pilots are trained that they have to accept comments from the aircrew, such as 'You have turned off the wrong engine!', because they may well be right. That is an interesting concept because it is something that we are trying to do in construction, where the general foreman on the site was the god – the person that no one would challenge – but, again, we are trying to train those people that they have to accept comments from the workforce. I found that very interesting.

We discussed working hours and came to the conclusion that the length of the shift and the number of hours that people have worked is not necessarily a prime concern. In some cases, the problems associated with changing shifts may be more of a hazard than asking people to work extended shifts. The example we had from process what that 12-hour shifts create benefits because there were fewer change-overs and, when there were change-overs, they were regular change-overs and one team would know the other. They would recognise each other and the hand-over would be much smoother. Once again, when working 12-hour shifts, one of the shifts, by definition, would carry over with the regular working day, so that other parts of the organisation that were working an all-day shift would neatly fit in. There were some advantages there which could – but not necessarily would – outweigh the disadvantages of asking people to work an extended day.

We considered, if it is not the working hours that can cause people to make mistakes, what is it? We concluded that people need some sort of enriching and stimulating work to negate any effects of adverse working practice, like shift work or extended work hours. That was the conclusion we reached. I personally made the point that I cannot understand how people can work on a production line which is not terribly stimulating. Perhaps those sort of routine and mundane tasks, which are inevitable in most industries, are rather a challenge, and they are the ones that we need to think about so that we can somehow introduce some kind of stimulation into the work pattern.

There is a point I should have mentioned earlier, on the question of change-over. We learned from aviation that there is a tool for changing over, from one shift to another, which was a form of mental checklist. It was actually acronym – PRAWN – although I cannot remember what the letters stand for. This apparently is rather a buzzword in the particular industry and they make you go through the five actions that the words suggest to them, covering five aspects of the change-over. That is a simple little trick, which could be of benefit in other situations.

Finally, we thought working hours were perhaps not all we should be considering. Increasingly, these days, thoughtful employers are looking at work/life balance. If you are asking people to work 12-hour shifts, knowing that they then have to spend a further two hours driving home, perhaps that should be taken into account. Working hours can impact on private hours.

John Turnbull: Thank you for that. When I first saw 'work patterns' on the agenda for this meeting, I was reminded of a retirement party from many years ago to which I was invited. This was not I hasten to add an employee of my former company. My dear friend of many years' standing said to me, 'Gosh, do you remember the days when we did not have to work in the afternoon?'

I am not sure that I should have said that, Vaughan, in front of an HSE policeman. Are you going to tell us about regulation and licensing, and what it takes to regulate a senior executive?

Group 3
Role of regulation & licensing

Vaughan Cole: Our topic is the role of regulation and licensing. Our group included: myself, Vaughan Cole from HSE; Kay Burt from the Atomic Weapons Establishment; Jonathan Early, Lloyds Register; Len Rogers from British Nuclear Group and Peter Waite from Entec UK. So we have a couple of nuclear specialists, a marine person, Entec has a broad base, and then of course the old regulator.

We started with the list of issues that were raised, which you should have in your packs, and decided there was too much there to cope with. We therefore decided to concentrate on the top three, which were: different regimes; the role of the controller; and the pros and cons. We did this both ways, structured and unstructured.

In the structured approach we tended, like all good regulators, to divide things into prescriptive and non-prescriptive regulation – prescriptive being that you say this, that and the other will be done, and non-prescriptive usually being a justification of how you go about doing a particular thing, to the satisfaction of the regulator.

Looking at the prescriptive to start with, the advantages of prescription were considered to be that it was clear and simple, and the application was appropriate – for instance, in driving.

The disadvantages were error by omission with no cost justification or argument and it tended to be worked to the lowest common denominator. It tended to be highly defensive which was applied to the barriers area as well.

Enabling factors were a fairly static sort of situation to regulate – a fairly static industry and an unchanging industry. The barriers to success were the fact that it tends to maintain the status quo.

If we now look at the permissive, goal-setting or non-prescriptive type of regulation, the advantages tend to be that safety responsibility was placed well with the operator – you remember the accountability - and this made the operator think about what they were going to do, which means humans in the control of context.

Disadvantages were that it was considered to be challenging for the operator and the regulator, because they both have to think. It is not particularly clear, and you get a diverse, non-uniform approach throughout any particular industrial sector.

Enabling factors necessary for success were a good safety culture; clearly defined management of objectives and expectations; and safety had to be placed in context. You needed well-trained, competent staff.

Barriers to this type of regulation were poor communication, the need for operator understanding and training, and the regulator needs skills.

So that was our structured approach.

We also had a non-structured approach to the group business, which might be a little easier to go through, although it may not be easier to understand. For non-structured, we start with goal-setting versus prescription and then we end up with the immediate question of who is the operator, and where are the human factors and elements. Are they with the regulator or are they with the controller? Who is the controller? Is it the control room operator, or the field operators? Or is it the maintenance staff? All of these people have changing roles. Or is it this thing called the controlling mind, that we tend to talk about?

An example that was given was that, sometimes during control people would worry more about an output than the actual safety implications – for instance, looking at the size of the flare on a process system, rather than the safety implications of the size of the flare.

Looking at the human aspects of regulations, the regulator was considered to have a fairly important role in intervening at the right time – intervening with valid questions and not with other questions which may be annoying in some respects. Of course, 'valid' and 'other' is dependent on which side you are, and irritating questions can be there for a purpose.

We came back to the example of the young team member, who may have a very important comment to make, but who is ignored. Another important factor was considered to be the need for authority in the shift, but that authority needs to be handled with due regard for other people's views.

We asked whether the regulator was a part of the team. The regulator has a struggle with their position as part of the team. Is the regulator too close to those they are regulating? Or do they need to be at arm's length? We looked at the possibilities of internal and external regulation. Who is the regulator? There was some reference to 'regulators R us', as it were – an internal, independent form of regulation, and not necessarily a completely different part of the organisation.

Then there is independence versus understanding the commercial reality, and this was considered to be important. Independence is a very important issue. Positive interaction was considered to be important and there was a great deal of discomfort, possibly, with partnerships. Once again, people were getting far too close on some issues and it is not clear as to who, actually, is calling the shots.

Is self-regulation effective? In an example of offshore regulation, with certifying authorities versus classification societies and other parts of the business, where there is a necessity to co-ordinate, independence is considered to be an issue, although it is not well-defined. The importance of independence is that it is shaped by people's culture and their previous experience, and their profession.

Investigation activity was considered to be important. We started drawing on examples from other parts of businesses and other very diverse technologies. For instance, there was the Colombia Shuttle investigation, where the overall objective was considered to be a challenge. If there is an exchange that goes on between the various sectors, and the

regulatory efforts of the various sectors, then this has to be done carefully – carefully managed and carefully applied because what applies in one sector will not necessarily apply in another.

Food regulation was discussed and it is interesting to line up next to each other the business of food regulation and technology regulation, and view the differences and similarities.

Societal concerns need to be addressed. There seems to be some indication that people are becoming more defensive and here, medics and seafarers were given as an example. What is more, it was considered that the operator, if put on the spot, would tend to take defensive action and, for instance, shut down in defence of his own position, as against continue operation with a certain amount of risk. However, we seemed to need some definition of shut-down and its importance.

Research was considered to be very important in that the risks in a piece of research, unlike a piece of operation – in an operational context, the risks might be well defined and established, and they can be addressed whereas, with research, the risks can be manifold, diverse and continuously changing. Shut-down procedures relating to these risks may in fact make the research pointless.

The point was made that shut-down is in fact a start-up operation, so that shutting things down does not necessarily make them safe. The example was given of train controllers, where the shutting down action was in fact the starting up action on another control – for instance, 'power on' is 'brake off'.

What should the regulator do? The controller responds very much to what we have gone through so far. There is a profit versus a safety balance to take into account. There are some Japanese and French nuclear controllers' thinking studies, related to some accidents in nuclear re-processing plants.

At this point, we started to talk about the designer, and where the designer versus the demands on operator balance take effect. Again, we ask, is shut-down safe, or do we keep going? The possibilities are that, after an incident, strange arguments may be developed for either keeping going or shutting down.

Completely ignored until this stage, we had not thought about the UK versus international regulation. At this point, we had a rather interesting maritime discussion. It turned out that German dentists are owners of most shipping and Chinese villagers train most crews of ships.

If we come back to where we started from, which was to ask what are the different regimes, we seem to be roughly splitting into goal-setting versus prescription and perhaps it is more generic than industry. How do these impact on the role of the controller? I would say they impact considerably, and the controller is very much affected by the regulatory regime in which they work. What are the pros and cons? We have gone through a few of them here. Thank you.

[Discussion follows]

Open Forum

John Turnbull: At this stage, I would like to ask you whether our breakdown of the issues surrounding the topic of the interface between complex systems and humans was a good one, or whether we have missed some key issues? Did the agenda fail in that sense?

Secondly, concerning the methodology of the day, has it worked and been effective? Thirdly, in these presentations we have heard a huge amount of commonality in what I would call the soft issues – the way to organise and treat people, issues of learning, team building and so on. That is very important but, in the course of today, have we uncovered any hard common issues which are worth exploring across the various domains?

For example on that last topic of regulation and licensing, here we are in an engineering academy, and engineers in this country do not need to be licensed. I can go out tomorrow and seek employment and, if I am employed, I can go and design a chemical plant. I can put CEng after my name, but it is meaningless and nobody has checked whether I can design a chemical plant or not, for the last 20 years. However, there are countries who license engineers to operate.

Tony Giddings has disappeared now, but medical practitioners do have the appropriate licensing and regulation. So that is different from us. What I am getting at is that there are some hard issues across domains, with quite big differences and factors. What are the pros and cons? I was certainly taught in the process industries, that licensing was next to the devil and that it would be a disaster. But now I wonder whether it may actually have made life much simpler if we had a licence to operate, and if that had some meaning. It might have helped us know what society expects. That was my third item. Have we uncovered any other hard common issue?

The final question I would like to ask is where should we, as an Academy, go from here in thinking about engineers and their role in this context? Nine-per cent of what I have heard in your feedback is stuff that engineers are not good at and certainly not trained to deal with, which is quite worrying.
Is there anything else that I should add to my agenda list?

Speaker: Where next? What happens after this?

John Turnbull: Yes, I will add that. Did we miss any key issues in our list for break-out? Did we get the right balance of issues?

John Harrison
(Nickleby HFE Ltd): It did not strike me at the time but, having gone through the process, there is one key area that it would have been advisable to include – especially given your position. In our group on automation we found that, rather than thinking of automation as something that will come through the door and what you should do about it. It should really be one of the consequences of the wider process of designing the whole system of the human organisational technological system.

The one key element that is missing from this list is the integration of both the hard and soft aspects of that broad system design within some sort of over-arching systems engineering process. Systems engineering is a relatively immature discipline compared with most of the engineering specialties. When people in this room talk about the engineers getting it wrong, it is the traditional specialties like the mechanicals and electricals – systems are far closer to understanding these broad issues. The way systems are procured and developed, there are huge issues because, typically, half the system is

provided by a different organisation from the other half. You get all sorts of cultural, political and contractual issues that complicate what should be a seamless whole of what, in fact, is usually a very complex system. Thus, integration is the key word that I would like to have included there.

We have heard mention of HFI and several industries are doing similar things. It is a difficult concept which is close to systems engineering, which is possibly the most important message for the engineering community.

John Turnbull: Thank you for that. Does anyone have any follow up on that specific point?

I agree that that is an important issue and it strikes me that, probably in this room, we understand what we mean by a system. This is a difficult issue. I was present at one of the committees in Parliament and an MP asked what a speaker meant by 'a system'. I must say that I was hugely impressed when the speaker produced from his pocket two pieces of wire, a bulb and two batteries. He connected them together and made the bulb light. He said that neither the battery nor the wire nor the bulb could produce light but, as a system, they could. So a system, he explained, is a collection of things which, together, do a great deal more than they can do individually. I am gobsmacked that people carry such simple but eloquent kit around with them like that!

More important than that, the penny dropped for one of the MPs in the room who said that what we mean is that we cannot finger a component. I thought that was a very astute observation: if the thing is done properly within the system, then when it goes wrong, it is misguided to try to finger one component. You have to look at the whole system.

Elizabeth Carver (BAE Systems Ltd): You have described the light bulb, the power source and the wiring as one little bit of a technological system, but there will be a people system and a process system on top of that, which makes up one part of the system. On top of that, there will be a whole load of those, a network of different systems that are networked together. So you will have a system of little systems built up. You have to deal with an understanding of the impact that one thing over here in this little bit of system has on that piece over there, in another part of the system. It is a very valid point that has been made there, and we need to take it on board.

It is a difficult thing to get your head around – human factors integration is always tricky, because people always think of it as the human factors itself, but it is not. It is trying to integrate all the bits in the system, over here and everywhere, that has a small element that will have an impact later on. There are always many of them and you need a systemic way of extracting those very early on in the design lifecycle.

John Harrison: To pick up an example of that. If you take the Zeebrugge disaster, at the headline level, somebody forgot to shut the doors but, at the technological level, there was no feedback of the door state on the bridge. At the procedural level, the tradition was to record when things were open, rather than when they were closed, so that the person on the bridge assumed that no report meant they were not open. At the management level, the real issue was that they were under huge management pressure that nothing was to get in the way of schedules. There, you have an example of a system nested from the organisation down to the technology, with procedures in the middle. There were contributory facts at all levels, but that picture does not come out from the superficial technology problem that the doors were left open.

John Turnbull: That raises another issue that we did not cover here, and rightly so because it is probably part of another chapter of the book. My namesake, Nigel Turnbull, the accountant who was head of the study group on corporate governance – risk management at a corporate

level – has done a good job of getting onto the agenda of boards the realisation that they really have to look at risk to the enterprise or business out there. It is just amazing to believe that a serious board – and it was an experienced board – could actually put pressure on those ships and their turnaround in that way. If only they had just spent 10 minute thinking about it. Hopefully, that is a situation that is improving as a consequence of the other Turnbull, in that boards are beginning to look at the risk to their enterprise from those failures, and the sort of pressures they put on operations.

Andrew Leggatt: I was just wondering whether co-design is not important in all of this. It is not about designing systems separately sometimes, but co-designing to design systems that work together. A part of that, of course, is the role of the human in the system. Part of the problem is the diversity that we have in terms of humans.

Elizabeth Carver: It is a minefield. When you actually set up a contracting environment where I am to give this contract to new people – they are all separate. This was alluded to earlier, and this lot over here set up their own standards for how they are going to do it, and those over there set up theirs. When you put the system together, lo and behold, this one is coming over here and we need something over there, and we actually manage almost to keep them separate. We are building the way we organise things, to build in these problems, so we have to step back to the way we procure systems.

As a customer, what do you want and how will you set up this partnership with all these different suppliers and different pieces of kit, to make sure that they do fit together? There are many examples in the railways about things being added on and it is certainly true in aircraft. You have an aircraft and you add on a bit – it was alright before you added the bit on, but then you have created a whole load of other problems. We have just touched the surface.

One of the points today was that we set up these conversations with people who would not normally talk to each other, and that is one success.

John Turnbull: I overheard one group discussing this issue of individual humans being different, in terms of personality and capability. When you think about it – and thinking back as an engineer – one assumed that there was a DIN standard person who would do a DIN standard job. We talk about fault tolerant systems but perhaps we need to talk of personality tolerant systems too.

Len Rogers
(British Nuclear Group): I am not sure whether we had sufficient discussion of how we actually gather data on human performance. We mentioned this morning that we are quite good at getting error data, but not at getting good practice data.

I also noticed a comment this morning about accident investigations attributing operator error, rather than contributing to understanding, and this is an area that could have been discussed more, to see how we could improve both the gathering and the quality of data.

John Turnbull: Are there any thoughts on that. If I understand you rightly, you mean on an ongoing routine basis as opposed to when the proverbial hits the fan?

Len Rogers: It is twofold. There is the routine feedback and in our industry, and I am sure in others, there are pretty good processes for error recognition, tracking and learning. However, we do not have particularly good processes for error avoidance or correction learning. This also applies to accident investigation in the sense that I would worry that we were starting to say, for example, that it is easier to blame an operator – because technology is perfect. I would question whether sometimes the operator is the root cause and whether we risk focusing too much on that aspect. I think it is two-fold – both the routine and the unique incidents.

Clive Tunley (EMS Risk Consulting Ltd): It came up in our discussion a number of times that when you actually blame an individual for a particular incident or accident, that is mainly just the first stage in understanding the true root causes. People tend to do things for a reason and so you need to look at why they have violated a particular rule. It might be because that rule is impossible to apply, or the procedures could be very poor. You cannot blame the individual because of that.

John Turnbull: But gosh, you get brownie points for finding the single cause, rather than making it complicated. Do you not find that?

Clive Tunley: That is the difference between applying blame and then actually learning from your accident and incidents data.

Vaughan Cole: On that point, during my presentation I probably did not make the point very clearly that whichever action you take, you could be in trouble. A good example is Three Mile Island TMI-2 accident, where the operators stuck slavishly to the rules and systematically shut down all the reactor protection systems – but they were doing it according to the rule book. You are not safe by sticking to the rules, necessarily.

Peter Brooker: It is either very amusing, interesting or sad that, when you were at primary school, you were given a test to add up numbers or something like that, or to write down dates in English history or whatever, and you made mistakes on that. Somehow, there is the belief that, if you are at school you can make mistakes and it is not a terrible thing but, if you are working as an operator in a firm, then making mistakes means you are a criminal. But people do make mistakes. The aviation industry has worked hard at distinguishing between the fact that people make mistakes, as a normal part of life, and when people make errors that indicate that they have actually behaved badly – that there is some kind of grossness in their behaviour.

We try to make sure that, for example, you have regulations about drink and drugs and control for that sort of thing. When you train people, you look for personality types that can cope with particular things. Air traffic controllers are chosen to be people who do not worry about things because, if you sat down and worried and agonised, you would make mistakes. You have to recognise that it is natural for us to do something wrong sometimes. You do not always say the right thing, sometimes you do not always communicate accurately, and sometimes you press the wrong button, but we have to find ways to compensate for that in system design.

John Turnbull: How many people in the room have worked in organisations, or do work in organisations, where bad news is welcomed and the messenger is not shot? How many work in organisations where you cay say, 'Things have gone wrong. Let me explain what happened. I had a part in it', and you are praised for doing that? [A few hands raised] There has been a change over the years but we still have a long way to go in terms of the attitude that you are describing.

John Harrison: Just as an anecdote related to that, I once worked for an organisation where, on my third day with the company, at a company meeting, the managing director encouraged us to do well and take risks and said this meant that failure was OK. The same man, a few years later, said that was the best, highest quality, losing bid we had ever put in. It was not the long knives. I do not know whether that culture is still around.

Elizabeth Carver: I just wanted to add a comment, following on a little on the standard operating procedures and the role of those things. Someone mentioned the pilots mixing teams up, so that they were not a team? This is quite interesting. If a standard operating procedure does not work, there should be a mechanism to try to update it and learn from why it does not work. That is what is missing – it is not that there is a standard operating

procedure or that people do not use it, but it is having the mechanism to understand and improve and have a feedback loop. It is really quite rare for people to say, 'This does not work this way. It is much better to do it that way – let us update our procedures.' That is the kind of growing, mature organisation. We have not touched on that too much, but that is the way to go.

Speaker: It might seem a strange idea, but you can have procedures for innovation, which is exactly what you are talking about. Quite a number of organisations have that, although I do not know whether we have this in ours.

John Turnbull: With no disrespect to my process contracting friends in the room, but traditionally in the process business the operating procedures are provided by the people who designed and built the plant. They say how it operates and what was intended. The operating company will take that and translate it into terms that are meaningful locally, together with the local rules.

One of the most impressive things I have seen in my time was a Japanese refinery where every shift had a section of the operating manual to re-write. The management had said to them that they knew what the designers had intended, but life was not like that. They therefore asked the shifts to re-write them in terms of what they actually did, and what worked on the plant. Within four years, they had some of the most impressive operating procedures going. They were terrific because they reflected the reality of how the system really behaved. That was the point that was made earlier that they actually act as operators interacting with the system too. It was not just the technology, but how it could be sensibly controlled.

Let us move on to today's methodology. Is there any feedback from you on the good, the bad and the indifferent about it? I suppose it was pretty boring, was it?

Elizabeth Carver: You just get the feeling, when you have these workshops, that if only you could have another hour with this group or that – you feel that there is much more to come out. That is my comment really – there is much more to come out from people and we have only really scratched the surface. I might be emailing some people, or phoning them.

John Turnbull: Were the groups the right size? I am serious about that because I have a fair amount of experience with these things. Once group size approaches 10, they become rather structured and formalised and people say what their management expects them to say, as opposed to talking about the reality. I shall take your response to be 'could do better'.

Peter Fearnley (HSE): A more specific point in our group was that we found the first part of the meeting with the three presentations was very helpful. They were very effective, in time and the amount of information, and they stimulated interest. That was particularly good.

The discussion time itself was perhaps perceived to be less good and less useful. Since we split up, however, the feedback from the other groups has been more useful, so you have to go through what was perceived to be a less useful process to get to that. It seemed to be more useful because you are getting information and insights. It is not terribly focused, however, and there are areas on which we would like more meat.

John Turnbull: We are operating on the basis that we needed to have made some mistakes in order to have learned from the experience.

My third issue was whether there were any hard, common issues across sectors, which came through. We have heard about the soft issues. I am fascinated by this whole shift towards team structures as opposed to the individual master of the ship or the guy who knew everything and could control everything. Some people describe it as the shift

towards the orchestra-type situation, where the leader is conducting skills rather than actually singing the song himself. However, that is a soft issue – but what about the harder issues?

The regulation and licensing territory is a hard issue which could be explored a little further and I would like to have heard more about that. Another hard and specific issue I have is that I have heard the word 'independence' around the groups. Liz and somebody else referred to airlines who do not let pilots and co-pilots become buddies, because they lose their integrity thereby and become sloppy. Clearly, in the airline business, there are situations like going into finals on a civil airline, where the two of them voting increases the quality of that decision enormously.

Lee Alford has had to leave early but I know that the PRISM group is coming up with thoughts that, perhaps in the process industries, there were certain situations where, if you put the wrong reagents together, it would be a disaster, and the process required people to actually read and understand the label before adding it. There were certain situations which were sufficiently critical that people are now thinking that perhaps we need an independent check on the operator's reading – so that we need four eyes as opposed to two eyes in those situations.

Bill Robinson has also disappeared, but is there anyone here from the railway business who can confirm this to me? Do the Japanese still have two drivers on their Shinkansen high-speed trains?

Malcolm Dobell (London Underground): I cannot answer about Shinkansen but I can certainly answer about some of the practices that we use on some of our fleets where there are critical activities to do with maintenance. Here, we require an independent person to check that the first person has done the thing right on bolts, where the torque setting is absolutely critical for the integrity of the joint. This is not a trivial activity because there are 11,000 bolts to worry about, and each one that is put in has an independent person checking that it is right. We then check the integrity of that bolt every 14 days, and we have 11,000 bolts. We feel the need to do that because it is so super-critical.

Quality assurance practice, and any decent quality process at a factory, requires critical activities to be inspected. Perhaps when we come to operating things and controlling activities, there might be some of those supercritical activities where you need to have an independent view of life. Equally, you might look to where you can design those out if you identify them during the design process for your system.

John Turnbull: Sure, but with the pressure on costs, one is always seeking to reduce manpower and all the rest of it. This idea that it requires two people to do one person's work does not go down well with many managements. It would be good to hear, across the board, how many situations there are where that is perceived to be proper.

Huw Gibson (Rail Safety & Standards Board): In Italy, they certainly have two drivers, as they do in Australia, but there is a real question as to the value of having two people doing something, and their independence. In terms of reliability, say, a pilot read-back of a controller's instruction is, if you like, an independent check which, we have found, can be as low as 50 per cent reliable. So we are spending all this effort doing this, because there are expectations between the people, because they are not truly independent. The actual reliability that you can get from checking systems is pretty poor and in some cases, looking at accident inspection, it is almost detrimental to have the two people doing it.

Speaker: I seem to remember from basic human reliability study tables and so on that the best you can ever possibly claim for an independent check as to whether the check was independent or not, was an order of magnitude improvement – and that was also dicey, and you could always be inspected on that. So it is not fantastic but at the same time, and to counter that, there are some fantastic CRM studies looking at the competence or the outcome from two-pilot crews who had flown together, as opposed to those pilots who had not flown together.

This data was collected by accident, strangely. There was a study in the US, set off by the National Transport Safety Board, which asked what was the effect of fatigue upon crews that fly together. They had two sets of crews, one set that had flown together over a sector, and another set that they put together, just as though they were new on a sector. They looked at the performance of these two groups, thinking that the fatigued crews would have more accidents. Strangely enough, those crews that had flown together that were fatigued – and they were rated as being more fatigued, having done eight to 12 hours – actually flew better. They made fewer incidents and they fewer precursors to accidents when they were put in emergency operating situations. Thus, there is evidence both ways and it is not a simple situation where you can say that if you have a second person, that is good, or if you have a second person, that is bad. It is more complicated than that.

John Turnbull: That confirms that my education was OK, when I was taught to avoid these perverse things called people – you cannot trust them to do anything as you expect them to!

Peter Waite (Entec UK Ltd): One of the issues concerning teams – and I do not know whether it is more important than having a confirming check, but it is certainly a very important feature that has come out from accident investigations – is having the right range of professional and operator competence within a team. If you have a particular skill missing, that is a very big issue and potential contributor to an accident.

John Turnbull: Are there any other 'hard' or not completely 'soft' issues that have arisen today, across sectors in the groups? Were there any surprises in that area?

Speaker: One of my discoveries was that we represent all sorts of different industries here, but the legacy issue is actually to do with culture and expectation in each of the different sectors. And while we can share all we like some of the tools of the trade, so to speak, simply transporting them into another industry is not a solution.

John Turnbull: Yes, point taken.

Vaughan Cole: That was the point we were trying to make, which was made during the discussion of regulation. I am sure my colleague will back me up when I say that you cannot just take one issue from one area and plonk it into another, and expect it to work. It has to be managed into the area and applied to the area.

Malcolm Dobell: I said to my friend from the HSE that you cannot just plonk Her Majesty's railway inspectorate into the HSE and expect it to work!

John Turnbull: What next, and where do we go from here? As I mentioned at the beginning, we will do our best to produce a meaningful record of these proceedings. You have covered a fair amount of ground and that will not be easy, but we have enough valuable material to collect and collate, which we will certainly do.

I failed to follow procedure this morning and I did not actually register, so I do not know what is in the registration pack. Did it include this Mickey Mouse matrix? [Yes] I have tried filling in the blanks on that and it is actually very interesting and revealing, particularly

relating to this point made about legacy. There are quite different structures in the impact of, for instance, hazards, the nature of the hazards and what is at stake. There are huge differences in the skills and background of people. All of these are hugely serious and important occupations.

I would like to make this less Mickey Mouse-ish and make it more realistic and real in its content. I shall do my best to do that, tapping any resource I can lay my hands on. If you have any views on it, or any insights into what might particularly go down the column by way of significant parameters which distinguish these occupations, those will be very much appreciated. I would like to make something of that sort part of our report back.

Are there any thoughts on what is next? Was this an interesting and pleasant one-off? Has it been the start of something new and provocative, which we need to think about? Do you have any views? Is there mileage in the process? Or did the people who designed this thing just get it totally wrong?

Louis Blache (Kings College, London): Some people have said that the ideas cannot necessarily be transferred from one industry to another but the interaction between the different groups is a useful function.

Elizabeth Carver: Could I just add something to this migration issue? Some of the ideas can be moved: the implementation will be different, and the way it fits, but the ideas can be moved. That is what we are thinking about, rather than that you just take a system and implement it – that is not really the idea. However, if there is something which you think will solve a problem over here, and it may fit here, you may have to change it but it is the idea that is important, and the problem that it is trying to solve, which you may not have challenged before. There are some problems which you have no idea how to solve and so, if another organisation has done something, then at least you are starting to build your option list.

Jonathan Earthy (Lloyds Register): Clearly, on the UK regulatory side, about three years ago now I tried to set up a forum for people – regulators – who were trying to assure the quality of human factors work. We got as far as establishing quite easily a common research agenda. We did not take it any further but we just shared that, because we could not find a parent organisation to plug this work into, but we felt that we needed a larger forum in which to do anything more significant. I would be happy to share that research agenda with you, if that would be of interest.

John Turnbull: That could be interesting, yes. As an academy, we certainly have a research mission which we farm out, if I may put it like that.

Speaker: I thought there would be room for presentations along the lines of those we had this morning, but obviously from different areas. Presenting more of the nitty-gritty from some of the varied areas that we have heard about would actually be quite useful. I would think that we should have at least one further occasion like this, perhaps tailored a little differently, to bring some of that information out for discussion. I would find that very useful.

John Turnbull: Following on from your earlier comment, are you saying there should be a little more priority given to the pre-packaged, thought-through presentational material, rather than the workshop exchange? You want real experience presented at the start.

Speaker: Yes, perhaps a little more emphasis on that. You need to have a blend of folk, but a little more, yes.

John Turnbull: It just remains for me to give you all my heartfelt thanks for coming here and participating so enthusiastically and energetically. It is a hard lesson for an engineer to take that people are more important than machines, but we live and learn!

In all seriousness, there is a deep-seated problem in the UK. Whether it is CP Snow and the two cultures, or whether it is the way in which we – in England, at any rate – go through this GCSE/A levels process, undoubtedly engineering and technology seems to be designed to attract rather narrow, introverted people like me, who are afraid to face fellow human beings. We engineers really want to work away, taking things to bits and putting them back together. But that is such a travesty of what the profession ought to be about. I keep trying to persuade the Academy to adopt a definition of engineering which has, as its first line, 'Engineering is primarily a social activity rather than a technical activity: it is about improving the quality of people's lives.' If we are unable to understand what people want, and communicate with them, heaven help us.

Conclusions & Recommendations

The three presentations to the workshop vividly and eloquently illustrated the differences between the sectors in their handling of the risks associated with controlling complex technology.

It was pointed out in the course of the workshop that one of the reasons for the differences is the way that failures are perceived. An airliner crashing can kill hundreds of people in a single event. Public outrage forces the industry to react and get its house in order – which by and large it has! In the health sector fatal errors occur patient by patient and therefore are relatively unnoticed by the wider community (see tThe Royal Academy of Engineering report on Societal Aspects of Risk for more explanation of the different perceptions). So the pressure on the health sector from outside is that much less. The Process Industry sits somewhere between these two.

There was general agreement amongst participants that it was beneficial to bring together people from a wide cross section of sectors to discuss and compare experience and practice. b But it was pointed out that practice could not be simply copied across from one sector to another. There are real and fundamental differences and there is also the question of legacy. Civil Aviation is a modern construct that started in effect with a clean sheet. Medicine has developed with centuries of tradition and that experience cannot simply be dismissed.

Key points made by the break out groups included: -

Automation and Software

- The process of automation generally involves looking at the behaviour of the machines or process and how this can be improved. Best practice involves looking at the total system of machine – human controllers and operators – operating environment. Only then can human and machine capabilities be optimised.
- The impact of automation on the controller's skill kit is very complex. The "intuitive" mental models derived from "driving" the machine and sensing its responses have to be replaced by more abstract and cerebral models.
- Modern software developments have vastly increased the reach of automation. The advantages of flexibility, lack of weight, potentially improved interface design and enhanced functionality are all well known. But there are also worrying disadvantages:-
  - susceptibility to viruses and hacking
  - vulnerable security
  - the temptation to continuously modify
  - increased complexity
  - off the shelf packages may lack the required integrity.

• The software industry does not seem yet to have developed a mature, and widely understood and accepted methodology. This can mean that each project becomes a one-off test bed.

Fault Tolerance

- While all agreed that "Fault Tolerance" in a system brings enormous benefits, it has to be developed in the context of the total "machine - controller - environment" system.
- It was emphasised that error tolerance does not simply allow operating continuity. It should also provide "space" for learning. When faults occur, then the lessons must be identified and acted upon. Fault tolerance that masks errors and leads to their being ignored is potentially very dangerous.
- More thought and discussion is required around the decisions on which "faults" to design for. For example should these include terrorism, potential suicides, malicious employees etc.?
- Linking together systems such as power distribution or air traffic control can change error tolerance levels. Also consideration needs to be given to the linkages themselves and their robustness and tolerance.

Training and Competence Testing

- Complex systems require team working. So training and procedures have to be directed at teams, not individuals.
- Good procedures anticipate problems.
- Unless there is continuous vigilance, procedures do not get 100% followed all of the time. Most of the time the deviations do not cause problems, u. Until one day an accumulation of failures produces a catastrophe.

- Effort must be put into overcoming the "silo mentality" and considerations of status inhibiting information sharing and willingness to respect the opinions and observations of everyone in the team.
- Simulators, whether of the hardware or software variety are of major assistance in training and testing.

Monitoring Operator Performance

- Much modern technology has changed the controller mode from proactive to reactive. This calls for a very different kind of performance. Care must be taken in defining clearly the operator role.
- An open incident reporting system facilitates performance monitoring.
- The value that an organisation (and the wider community) places on the operator's role is very influential in obtaining good performance. Pilots were contrasted with engine drivers in this regard.

Organisational Learning

- Interfaces should be designed so that their layout, colour scheme etc. conveys functionality. Humans feel intuitively that big, bright things are more significant that small grey ones!
- Organisations do not naturally acquire a culture that encourages learning. It has to be stimulated, cultivated and sustained.
- Truth will suffer if the focus is on fear of failure and the quest to pin blame.
- System failures have a multitude of causes. Attempts to find a single cause will stifle a key opportunity to learn. All of the causes should be identified, set out, and learnt from.
- Positive effort is needed to overcome complacency. Reactions such as "We are different" or "It won't happen here" are huge barriers to learning.

Work Patterns

- Team working is crucial. But consideration needs to be given whether a specific situation will benefit from a team who know each other well and have worked together over a long period. Or does the situation require a level of integrity such that it can only be obtained by mixing up the teams so that closeness and familiarity does not breed carelessness and shortcuts in procedures.
- It is dangerous to be simplistic about shift working. Different patterns can work in different situations, b. But resource should always be provided to ensure a good shift handover.

Regulation and Licensing

- Prescriptive regulation has the advantage of being clear and simple. But it tends to be defensive, conforms to the lowest common denominator and to maintain the status quo.
- Non-prescriptive regulation places a heavier burden on the operator, which is arguably good. But it will result in a diversity of approach.
- There is a fine line to be drawn between a regulator who is close to an industry and knows it well, and one who loses objectivity and independence.
- Self regulation can be very effective, but it is very demanding and should always involve independent agencies as part of the process.
- There is concern that external pressure from regulators, or the broader community can force operators to be defensive. Simply shutting down a system at the onset of problems may not be the best course of action from a safety, economic or experience-gaining viewpoint.

Participants were invited to complete a feed back questionnaire on the workshop. About 40% of them did. The overall evaluation of the workshop was that it had been a success and was thought to have been very valuable. It addressed the issues and was generally found to have been informative and relevant. We can conclude that the workshop satisfied the expectations of the attendees.

The Royal Academy of Engineering's aim is to promote engineering excellence. And certainly the workshop did highlight a significant number of key issues that engineers must address in order to successfully introduce complex technologies that match human capabilities and aspirations. As with so much of the Risk Project to date, there was a heavy emphasis of the "softer" social issues and an implied concern that much modern technology does not address the real needs of people, be they the "clients" or the operators.

The workshop did confirm the earlier report's conclusions that there are wide differences in practice between different sectors. Participants placed a lot of value on being able to get together with colleagues from quite different sectors and

environments. What is less easy to evaluate is just how significant this is, and. It was disappointing that we did not uncover much hard evidence of the benefits of experience sharing or transfer of best practice from one sector to another. However, this may have been due to the one off nature of the event, the agenda and, as one participant put it, the attempt to cover a great deal of ground in a very short time span.

Follow up is clearly called for and we must collect data and opinions to help decide what form that might take. In the first instance the Academy should obtain the opinions of leading organisations in a variety of sectors on how they perceive the issues involved in ensuring the effective implementation and subsequent operation of complex engineering systems. Analysis of these data from the field will be invaluable input to help shape the next stage of the project.

Appendix 1

Members of the Planning Group

Mr John Turnbull FREng (Chairman)	Royal Academy of Engineering
Eur.Ing Louis Blache	King's College London
Ms Elizabeth Carver	BAE Systems
Mr Vaughan Cole	HSE
Professor Andrew McGettrick	University of Strathclyde
Dr Gerard Panting	Medical Protection Society
Mr Bill Robinson	Rail Safety & Standards Board

Secretariat

Mr Anthony Eades
Mr Nicholas Wilson

Appendix 2

Workshop Registrants

Mr L Allford (Speaker)	PRISM
Wg Cdr D Appleton	Defence Logistics Organisation
Eur. Ing L Blache	King's College London
Professor P Brooker (Speaker)	Cranfield University
Mr R Burden	Civil Aviation Authority
Ms K Burt	Atomic Weapons Establishment
Ms E Carver	BAE Systems plc
Mr V Cole	HSE
Ms H Conlin	Kvaerner
Mr T Crawford	Metronet Rail
Mr P Cullen	Edmund Nuttall Ltd
Mr P Dawson	Defence Logistics Organisation
Mr J Demalgalski	National Air Traffic Services
Mr M Dobell	London Underground Ltd
Mr A Eades	Royal Academy of Engineering
Dr J Earthy	Lloyds Register
Dr P Fearnley	HSE
Ms G Fletcher	National Patient Safety Agency
Dr H Gibson	Rail Safety & Standards Board
Mr A Giddings (Speaker)	National Clinical Assessment Authority
Professor K Hambleton FREng	University College London
Mr J Harrison	Nickleby HFE Ltd
Professor M Harrison	University of Newcastle
Mr R Harvey	QinetiQ
Mr J Hatto	J & W Hatto Services
Dr R Hibberd	Bath University
Dr C Horbury	London Underground Ltd
Professor P Johnson	Bath University
Mr P Jones	Lincoln County Hospital
Dr A Kaposi FREng	Kaposi Associates
Dr J King CBE FREng	Imperial College
Mr A Leggatt	BAE Systems plc
Ms P MacDonald	Atomic Weapons Establishment
Professor A McGettrick	University of Strathclyde
Mr M Neale OBE FREng	Neale Consulting Engineers
Dr M Nicholson	University of York
Mr A Nunnery	Balfour Beatty
Dr G Panting	Medical Protection Society
Mr P Rayson	Technology Innovation Centre
Mr W Robinson	Rail Safety & Standards Board
Mr L Rogers	British Nuclear Group
Mr D Ross	Edmund Nuttall Ltd
Mr M Self	London Underground Ltd
Mr I Shin	Bath University
Mr A Trenchard	Honeywell
Mr J Turnbull FREng	(Chairman) Royal Academy of Engineering
Mr P Waite	Entec UK Ltd
Mr N Wilson	Royal Academy of Engineering
Professor W Woods FREng	Queen Mary College, London

Appendix 3

Workshop Agenda

09.45 am	Registration
10.00am	Introduction by Mr John Turnbull FREng
10.15am	The Civil Aviation Approach: Professor Peter Brooker, CAA Professor of Air Traffic Management & Environmental Policy, Cranfield University, School of Engineering
10.30am	The Changing Operating Theatre: Mr Tony Giddings, National Clinical Assessment Authority, Surgical Advisor to NHS Modernisation Agency
10.45am	Process Industries Safety Management (PRISM). Views on Experience Sharing. Mr Lee Allford, Operations Manager, European Process Safety Centre
11.00am	Questions
11.15am	Break Out Group Discussions • Impact of Automation • Training & Competence Testing • Role of Regulation & Licencing • Monitoring Operator Performance • Software Vulnerabilities • Fault Tolerance Systems • Organisational Learning • Working Patterns
12.30pm	Working Lunch (in break out group rooms)
13.30pm	Plenary Session – feedback from break out groups
15.00pm	Open Forum
15.45pm	Summary & Concluding Remarks by the Chair
16.00pm	Refreshments

Appendix 4

Results of Feedback Questionnaire for Humans in Complex Engineering Systems Workshop

Number of respondents as at 15th November 2004 = 18

Question 1 **How did you hear about this event?***

Direct mail	5
Email	6
Web	0
Other	9

* Some respondents ticked more than one box

Question 2 **Do you consider that the event addressed the appropriate issues?**

Yes	18
No	0

Question 3 **Who were the speaker(s) you were most interested in coming to hear?**

P Brooker	1
T Giddings	7
L Allford	2
All	5
Not relevant	1

Comments included:

'Giddings the most interesting
'Good diversity, all interesting'
'Meeting wide range of delegates very good'
'All three, but very much enjoyed Giddings'

Question 4 **How would you rate the value of the break out groups?**

Very helpful	4
Helpful	11
Fair	3

Question 5 **Overall, how informative/relevant did you find the event?**

Excellent	2
Good	13
Fair	3
Poor	
Unacceptable	

Question 6 **Were you satisfied with the practical arrangement/organization of the workshop?**

Invitation/registration process

Excellent	4
Good	10
Fair	2
Poor	
Unacceptable	

The facilities provided by the Academy

Excellent	6
Good	9
Fair	1
Poor	
Unacceptable	

The sound, light & projection

Excellent	6
Good	11
Fair	
Poor	
Unacceptable	

The refreshments & lunch

Excellent	3
Good	11
Fair	3
Poor	
Unacceptable	

Question 7 **What topics would you like to see as subjects for Future Academy Risk events?**

'Discovery of areas in regulation which may benefit by sector transfer'
'Systems engineering'

'Engineers role in risk management'

'Human factors integration in design process'

'Method of assessing risk or adequacy of safety arrangements with respect to Human Factors in Engineering Systems'

'Design and/or engineering education – does risk assessment/reduction start here. Especially with regard to human factors.'

'Risk tolerance & assessment of risk'

There is a lot to be said for taking a risk-based approach to the Management of Human Factors. That might perhaps be a useful thread in a future event'

'Monitoring human activity to identify problems ahead of failure'

'Impacts of demographic change within the work force i.e. ageing population, part-time working etc., and how they may change risk profile(s)'

'

The way forward- how to take HF out to a wider engineering population'
'Further exploration of human issues. Why do people take risks?'

Question 8 **If you have any general comments about the event, please give them below.**

A lot to deal with in a short time, on an issue which must be important to the Academy and society.'

Good'

'HFI & systems engineering as used in rail tends to focus on engineering Ergonomics aspects of HF, e.g., design of HMI, LR layout. Does take high level view of impact of proposed change to sociotechnical system (i.e. not necessarily appropriate to engineer & sociotechnical system). Systems engineering – mechanistic. Sociotechnical approaches organic.'

To bring together a good range of people from a wide range of industries/sectors etc., & various experiences very helpful…. Sum greater than individual elements1 Well done.'

Would liked to have known my teams biogs. In advance of arriving at team! – chairing by the seat of my pants!'

'Enjoyed it'

'Thanks'

'It provided an excellent opportunity for networking and open exchange of information between people from diverse backgrounds'

'Very worthwhile – should be the first of a number rather than first and last'

'Very useful to discuss with non-construction professionals. Most workshops on matters such as these perhaps have too narrow an approach'

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