Performability: Pedagogical Perspectives

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Abstract: Links of performability to environmental health and safety are developed through policy and legal pressures as well as through illustrations from some major disasters. The human factors inherent in performability can be addressed in part though education and training, and distance teaching has an important role to play. Approaches to providing this education are outlined together with some measures of performance.

Key Words: safety, environment, management systems, distance education.

1. Introduction

The concept of performability was first applied by Meyer [1] in 1978 to evaluation of highly reliable aircraft control computers for use by National Aeronautics and Space Administration (NASA) in the US. While the word appears to be simply relating to some measure of performance, in reality, performance contributes only half of a performability evaluation, which is sometimes defined as combined performance and reliability. Others use dependability. This is a broader term that includes reliability as well as availability, safety and security. Gradually, the concept of performability was applied to increasingly wider disciplines beyond the original applications of computing and communications systems. So now, the concept can be applied more widely to other degradable systems. To quote the specification for this Journal [2],

‘Performability is meant to reflect a holistic view of designing, producing and using a product, system or service, which will satisfy the requirements of a customer to the best possible extent and is dependable, safer and sustainable. In other words, such attributes would reflect a designer’s entire effort in achieving sustainability for a dependable and safe product... Therefore, it is meant to reflect all the three major attributes of a product, system or service, namely, 3-S, denoting Survivability, Safety and Sustainability.’

The sustainability and holistic elements in performability may be likened to concepts in legislation such as the Integrated Pollution Prevention and Control (IPPC) Directive [3], which is about minimising pollution from various point sources throughout the European Union. It is evident that current European production and consumption patterns are certainly not sustainable [4]. While great improvements have been achieved in industry regarding several major polluting substances, and that gradually the environmental impact has shifted towards so-called diffuse sources of pollution (such as traffic and household consumption of chemicals), industrial production processes still account for a considerable share of the overall pollution by greenhouse gases, acidifying
substances, volatile organic compounds and waste in Europe. Hence it is very important to reduce further their contribution to ‘unsustainability’. In the context of IPPC, ‘integrated’ means that the permits must take into account the whole environmental performance of the plant, i.e. emissions to air, water and land, generation of waste, use of raw materials, energy efficiency, noise, prevention of accidents, risk management, etc. There are clear links with the aim of this journal, which is to bring synergistic interaction between those working in the area of survivability (often reflected in attributes like quality, reliability, maintainability and availability) and those working in the area of safety and sustainability (often reflected by the attributes like dematerialization, minimum energy, minimum wastes and pollution prevention measures). Developing products, systems and services having minimum life cycle costs and maximum performance cannot be achieved without this integration nor can effective performance across the spectrum of environmental health and safety.

Likewise, health and safety are essential elements in terms of the quality of work, and feature among the indicators adopted in the wake of the Commission’s communication ‘Investing in quality’ [5]. The Community’s policy on health and safety is based on preventive approaches bringing in all stakeholders, including workers themselves, with a view to developing a genuine culture of risk prevention, the aim being to anticipate risks and bring them under control [6]. Creating a controlled work environment means improving everyone’s knowledge of risks through awareness and training. The timing of the European strategy is over a shorter time scale (2002/6) than the UK strategy ‘Revitalising Health and Safety’ [7] that looks forward to 2010. Almost two thirds of responses to the consultation exercise leading to this latter strategy focused on the need to raise awareness of health and safety among employers, workers and the general public, with education standing out as a means to raise this awareness. It has been noted that a close association between safety and reliability has existed since the earliest times [8] and both are associated with risk.

2. The Need for Performability Education and Training

Organisations operate in an aggressive, competitive environment, and operating near the boundaries of established practice especially under financial pressures may cross the limits of safe practices – or push performability to its limits. Official reports on various incidents over the years have demonstrated this with a few examples being given in the Appendix.

Concepts of risk, and risk management are used in many diverse fields, but their meaning differs in different disciplines. When we say we are going to take a risk we mean that we are prepared to take a chance of an adverse consequence in the expectation of a benefit. Implicit in that interpretation is that risk reflects both a likelihood of ‘harm’ and a measure of the consequence. In everyday life, however, it is consequence that may be paramount in our mind rather than likelihood. Commonly we associate risk with some aspect of ‘loss’, but it is important to recognise that in financial matters, risk attempts to quantify the probability of loss as contrasted to the probability of gain. The emphasis here is on a potential benefit. The challenge is to balance the chance of benefits against the chance of suffering loss in some form. Commercial success can depend on exploitation of the benefit from operating at the fringes of the usual, accepted practice.

Examples in the Appendix illustrate where performance and reliability were deficient, and it is almost inevitable that errors (especially involving human factors) will happen
with consequences for environmental health and safety. Through the 1970s and 1980s public attention focussed on the human contribution to system failure. Flixborough, Seveso, Bhopal, Chernobyl etc. increased awareness that human intervention could cause or exacerbate major accidents. In consequence, human error models were developed to categorize and explain operator failure during major accidents. Understanding of human error has evolved over the years. Investigations into the Piper Alpha and other accidents revealed managerial factors rather than the individual's contribution through erroneous actions. The emphasis has moved from individual performance to the organizational environment that creates latent opportunities for failure. For example, Reason [9] records that the ‘person’ and the ‘system’ approach to the problem of human fallibility exist. The person approach focuses on the errors of individuals, blaming them for forgetfulness, inattention, or moral weakness. In contrast, the system approach concentrates on the conditions under which individuals work and tries to build defences to avert errors or mitigate their effects. High reliability organisations, which have less than their fair share of accidents, recognise that human factors must be harnessed to avert errors, but they work hard to address these factors and are constantly preoccupied with the possibility of failure.

It is evident that human factors played a role in the above and many other disasters and so is a key element of performability. Evidence also suggests increasing human influence on global climate, with implications for energy efficiency that depend upon the actions of individuals. Human factors also play an important part in implementing cleaner production for IPPC as well as for dealing with health and safety in the workplace. Hence, it is not surprising that training, as a means of influencing human behaviour, forms an important element of recognised management systems (Table 1). It is noteworthy that under the revisions to ISO14001, Section 4.4.2 has been extended to incorporate all persons performing tasks for or on behalf of an organisation, and includes contractors, sub-contractors, temporary staff and remote workers. All must have an appropriate assessment for their potential to cause a significant environmental impact and of the associated competence required.

It is clear that there is no escaping the need for education and training to meet these employment needs with ‘best practices’ often embracing elements of performability. A question that remains are how can the transfer of knowledge and skills be done efficiently and effectively?

3. Some Pedagogical Perspectives

Pedagogy is the art or science of teaching, from the ancient Greek paidagogos, the slave who took children to and from school. Pedagogy is also sometimes referred to as the correct use of teaching strategies. In the pedagogic model, teachers assume responsibility for making decisions about what will be learned, how it will be learned, and when it will be learned - teachers direct the learning. Since the 1970’s, Knowles formulated a comprehensive adult learning theory, asserting that adults require certain conditions to learn [10]. He used the term andragogy, initially defined as ‘the art and science of helping adults learn’ but which has since taken on a broader meaning as an alternative to pedagogy being learner-focused education for people of all ages.
Table 1: Training is Identified in Management Systems Standards

<table>
<thead>
<tr>
<th>BS EN ISO 14001:2004</th>
<th>BS-OHSAS 18001</th>
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<tr>
<td>4.4.2 Competence, training and awareness</td>
<td>4.4.2 Training, awareness and competence</td>
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</table>

The organization shall ensure that any person(s) performing tasks for it or on its behalf that have the potential to cause a significant environmental impact(s) identified by the organization is (are) competent on the basis of appropriate education, training or experience, and shall retain associated records. The organization shall identify training needs associated with its environmental aspects and its environmental management system. It shall provide training or take other action to meet these needs, and shall retain associated records.

The organization shall establish, implement and maintain a procedure(s) to make persons working for it or on its behalf aware of:

a) the importance of conformity with the environmental policy and procedures and with the requirements of the environmental management system,

b) the significant environmental aspects and related actual or potential impacts associated with their work, and the environmental benefits of improved personal performance,

c) their roles and responsibilities in achieving conformity with the requirements of the environmental management system, and

d) the potential consequences of departure from specified procedures.

Personnel shall be competent to perform tasks that may impact on OH&S in the workplace. Competence shall be defined in terms of appropriate education, training and/or experience.

The organization shall establish and maintain procedures to ensure that its employees working at each relevant function and level are aware of:

- the importance of conformance to the OH&S policy and procedures, and to the requirements of the OH&S management system;

- the OH&S consequences, actual or potential, of their work activities and the OH&S benefits of improved personal performance;

- their roles and responsibilities in achieving conformance to the OH&S policy and procedures and to the requirements of the OH&S management system, including emergency preparedness and response requirements (see 4.4.7);

- the potential consequences of departure from specified operating procedures.

Training procedures shall take into account differing levels of:

- responsibility, ability and literacy; and
- risk.

Now, andragogy-pedagogy represents a continuum rather than discrete alternatives. Issues to be addressed in application of the andragogic model include:
learners need to know why, what and how;
the self-concept of the learner – desiring autonomy and self-direction;
prior experience – a resource and the basis of mental models;
readiness to learn is life-related and a developmental task;
orientation to learning is problem centred and contextual;
motivation to learn has an intrinsic value and personal pay-off.
Application of some of these features will be developed shortly.

Meeting Professional Development Needs

Professional development is an important feature of adult learning. In a wide ranging examination of education and training in environmental protection, the need was identified to help graduates evolve into ‘leading problem solvers’ [11]. It is essential for educational establishments to satisfy the needs of employers. However, Dominik et al. [12] suggested that while most engineering has environmental aspects, the general education of engineers in natural environmental sciences and global environmental problems may be limited. They suggest that teaching focuses on finding solutions for immediate environmental problems (energy efficient technologies, waste management, clean-up) while neglecting a more holistic view. Environmental curricula in other universities teach natural or socio-economic aspects of environmental science according to faculty. While specialisation is logical and desirable, students need to understand the more technical aspects of environmental protection and management including technical limitations and economical viability of projects. The broad performability approach seems absent.

Translating needs into action by distance learning

Distance education in the context of a teaching and learning process is where the educator and learner are removed from each other in time and space and typically involves a combination of different media [13]. While historically this form of education may have been viewed as a ‘second class’ option, this is no longer the case and is widely available as a stand-alone option or complements conventional approaches.

In an assessment of the relative merits of face-to-face against distance teaching, Burt [14] observed that a minimalist definition of distance education identifies it as education that occurs at a distance, with a relative absence of face-to-face communication. Modern information technology makes distance education less distant. One combination is known as blended learning in which distance methodology in the form of e-learning opportunities are blended with face-to-face learning in coherent ways. More meaningful debate centres on whether the medium has a certain form, involves technology and includes interaction, independence, openness and critical reflection. Distance teaching enables all and increasingly conventional universities embrace elements of distance media, often in association with conventional approaches.

A leader in distance education is the Open University, ranked as one of the top five universities in the UK [15]. It offers many environmental courses that may be taken in isolation to satisfy specific professional development needs. Several courses from the undergraduate programme from the Faculty of Technology may be combined leading to a Diploma in Pollution Control as well as to a B.Sc. degree. Figure 1 indicates some of the courses, each of which is identified by a characteristic code number for brevity. Features of the first year undergraduate course have been described elsewhere [16].
The postgraduate programme in Environmental Decision Making is also indicated in Figure 1. To quote the prospectus,

‘The Environmental Decision Making Programme is less about ‘the environment’ than it is about people and we focus on the decisions and actions people make which affect the environment.’

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**BA/BSc Environmental Studies**

- Diploma in Pollution Control
  - Including:
    - Environmental control & public health (T237/T210);
    - Environmental monitoring, modelling & control (T303/T308)

**Working with our environment: technology for a sustainable future** (T172);

- Renewable energy (T265);
- Innovation: design, environment & strategy (T302), etc

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**PG Diploma/MSc in Environmental Decision Making**

- Taught modules include:
  - Environmental Decision Making: A Systems Approach (T860/T863);
  - Enterprise & the Environment (T862);
  - Integrated safety, health & environmental management (T835)
  - Environmental Ethics (T861)

⇒ MSc research dissertation (T802)

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**PhD**

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**Fig. 1: Some Technology Faculty Contributions to an Environmental Curriculum**

(parentheses show course codes)

It is aimed at the needs of environmental professionals and integrates the performability characteristics of survivability, safety and sustainability with a view of enabling participation in complex decision-making issues.

A core course in this programme, Enterprise and the Environment (T862), is based very much at the level of businesses and has a focus on pollution prevention and clean technologies through resource efficiency, but in the context of socio-economic and management systems frameworks.

A manager in any reputable organisation of today is expected to manage resources in an effective manner with the ultimate goal of bringing profit to the organisation or running it within the financial resources provided. Achieving this requires an awareness of, and responsibility for, a wide range of areas including personnel, planning, finance, health & safety, environmental issues, customer liaison and the delivery of a product or service. Obligations are imposed by legislation, by stakeholders, customers, the community and employees. Diverse interests such as these are addressed in optional modules in the programme such as integrated safety, health and environmental management (T835) as shown in Figure 1. This is a multi-disciplinary area embracing scientific, engineering, and social and policy issues, with clear links to the 3-S elements as well as to reliability and other features of performability. No individual can be expert in all of these disciplines, but the SHE manager should be able to appreciate the different perspectives and to recognise the inevitable trade-offs. The course components are shown in Figure 2.
The course embodies the plan-do-check-act cycle that is the basis of environmental as well as health and safety management systems and follow the scheme:

- **Plan** – Analyse the current situation, establish objectives and set targets with plans being developed to achieve them.
- **Do** – implement the plans
- **Check** – measure results. ‘When you can measure what you are speaking about and express it in numbers, you know something about it ...’ is a saying attributed to Lord Kelvin.
Act – correct and improve the plans and how they are implemented. Learning from mistakes helps to improve plans in order to achieve a better outcome next time.

It was noted earlier that the orientation of adult learners is towards problem centred learning. Practical problem solving covers a wide range of situations, and with the advent of management systems for environmental health and safety issues, this aspect is essentially anticipatory. It involves identifying significant risks where improvements can be made to avoid future problems. So problem solving education should deal with this anticipatory aspect as well as solving problems already in existence. In terms of solving the problem, many may be able to suggest viable options, but this approach can be inefficient and expensive. The ideal is to have sufficient insight to the problems that make up a situation, and then to match against practicable solutions. Both practitioners and educators face great challenges in meeting these demands, and project work based on real life issues can be useful here. Course assignments do this by building on topical events as illustrated in Table 2 and elements of performability and of the andragogic model noted earlier are evident.

4. Performability of Courses - Quality in Content and Delivery

The Open University approach involves supported distance teaching methods, with emphasis on the support element provided by tutors during the presentation of a course. Communication channels are provided by mechanisms such as tutorials, telephone, and an e-desktop, with access to conferencing as well as electronic resources, library facilities and so on (Figure 3).

Fig. 3: The e-desktop for the Course ‘Enterprise and the Environment’

Quality during presentation is maintained by systematic monitoring of the work of tutors to ensure accuracy in assessment and appropriate distance teaching techniques. The course
approval and development systems at the Open University are rigorous, and all proposals are closely examined in relation to educational objectives and the means of achieving them. The course team approach to course development involves constructive criticism of draft materials before professional editing. All courses are assessed externally before presentation, and have an external examiner during presentation, while degree programmes have external advisers on the Programme Committee.

Table 2: Themes from Integrated Safety, Health and Environmental Management

<table>
<thead>
<tr>
<th>Course context</th>
<th>Extracts from representative assignment questions</th>
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<tr>
<td>Block I explores lessons from examples of major disasters – with those in Appendix 1 illustrated in video records of BBC News bulletins. Learning lessons from the past fits with the need to anticipate problems before they occur, and plan for prevention rather than remediying problems. Both health and safety and environmental protection prioritize prevention and require the root cause of problems to be addressed.</td>
<td>The Report on the investigation of the escape of Vinyl Chloride Monomer onboard Coral Acropora, Runcorn, Manchester Ship Canal, 10 August 2004 (Marine Accident Investigation Branch, Report No 4/2005, March 2005) lists various actions taken by the different parties to prevent a recurrence of the incident. Analyse these points to identify whether each addresses human, hard and/or system errors, justifying your views.</td>
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<tr>
<td>Measure- is a particularly important approach in fields in which value judgements and opinions play a role the equal of facts. Only by deriving measures can we understand the issues better and seek to balance one against the other. However we must understand the data and interpret them correctly.</td>
<td>Vinyl chloride is typical of chemicals that get adverse headlines through concerns about risks of chlorinated substances, although such concerns may be more emotional than scientific…. Interpret the findings from a study comparing how toxicologists and the general public agree on statements about chemicals and relate them to principles of risk communication.</td>
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<tr>
<td>Block II develops one of the specialized areas in more detail - toxicology for health and environmental protection. Uncertainties in measurement are introduced in the toxicological area and in standards setting.</td>
<td>A drinking water supply has a concentration of vinyl chloride of 0.014 mg/l. …Carry out a risk assessment to determine the human exposure to vinyl chloride for using the data given and specifying any assumptions.</td>
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<td>Block III takes a quantitative approach to risk assessment through techniques that include:</td>
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<td>• Epidemiology:</td>
<td>Various processes are carried out around a shipping berth, including welding, spray painting etc…. You decide to conduct a formal study of asthma in this workplace and consider research methods including a randomized trial, questionnaires, cohort and cross sectional study. Distinguish these options and outline their relative merits.</td>
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<tr>
<td>• Monitoring</td>
<td>In the scenario, only ‘grab’ samples were possible rather than continuous sampling. Discuss the implications of this approach in terms of representing air quality?</td>
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<tr>
<td>• Modelling</td>
<td>The report refers to a modelling exercise carried out by the Health and Safety Laboratories. …..Carry out your own assessment of the scenario;</td>
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</table>
Quantified risk assessment

In the context of the scenario, generate a fault tree with the top event ‘Large release of vinyl chloride monomer’.

Control - When problems have been identified and possible solutions proposed, the SHE manager must be able to understand the options and identify the most appropriate. The topics covered in Block IV include:

- Fire prevention and control
  Summarise the selection principles for equipment used on a vessel such as Coral Acropora carrying a flammable cargo such as VCM to minimize ignition risks.

- Machinery guarding

- Personal protective equipment
  Human factors played their part in the causation of the incident on Coral Acropora as reported. Apply the principles of human error analysis to the scenario. In the conclusions of the Report it is stated that Personnel from both the vessel and the shore did not wear the proper personal protective equipment. Identify the hazards in the scenario and indicate appropriate personal protection equipment to address the associated risks. Justify your conclusions.

Working through the coordinated actions of everyone is an important role of any manager. Block V looks at ways of harnessing the combined efforts of everyone through training and integrated management systems.

Give a critical appraisal of management systems to the scenario in the Coral Acropora incident. Refer to how management systems are established and apply elements to specific issues described in the report.

Should all else fail, the course concludes with emergency preparedness including business continuity.

Consider an organization with which you are familiar and identify what could come under the heading of ‘harm’ and how the risk is managed…

However, students are important arbiters of quality, and a recent comment on a T835 course conference speaks for itself:

The course material is meticulous and written really well. I actually looked forward to reading the next page!!...The course has released me from the boring basic work and sent my motivation sky high. I can’t wait to complete my diploma and get involved with more meaty stuff at work.

5. Conclusion

Education and training is an integral part of performability and must be considered across the whole life cycle (from cradle to grave). Lifelong learning can be achieved effectively and efficiently by distance teaching. At the professional level in the cycle, we are often dealing with adults with considerable and varied experience and knowledge. Distance teaching can tap this vast resource and develop it to the benefit of students and the organisations in which they work.

In common with the wider Open University innovations in distance teaching media, the courses described here are always evolving. Increasing use of the Internet offers new
opportunities to reduce distances, to share knowledge and experience and to provide access to educational resources. Like the scope of performability, distance teachings have no boundaries and may stand-alone or complement conventional higher education.

**References**


Appendix: Some Major Disasters and Associated Implications

<table>
<thead>
<tr>
<th>Incident</th>
<th>Date</th>
<th>Observations/implications</th>
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</table>
| Flixborough | 1972 | Some key issues from this incident were the need:  
- to control modifications  
- for companies to employ people with the right expertise and to consult them  
- to reduce inventories, control plant layout and location and building design  

After Flixborough, an Advisory Committee on Major Hazards was set up, and concluded that the dominant factor in the control of major hazards was management. |
| Seveso | 1976 | The notorious incident at Seveso in Italy led to the so-called Seveso Directive, implemented in the UK by the Control of Industrial Major Accident Hazards (CIMAH) Regulations. Weaknesses in terms of implementation led to a new Directive for the Control of Major Accident Hazards involving Dangerous Substances (COMAH). Key elements included emphasis on safety management systems, land-use planning with risks to the environment as well as to people, and emergency planning. |
| Bhopal | 1984 | While there were technical causes contributing to the incident, human factors were important. Negligence was tolerated in the Bhopal culture and there was a lack of safety consciousness among workers and management. Morale was low because of the plant’s failure to achieve profitability, and this contributed to carelessness. Low morale encouraged the best employees to leave, the number of operators on the MIC plant being halved between 1980 and 1984. |
| Chernobyl | 1986 | Examples of improper management, included:  
- Improvisation because of supply problems.  
- Difficulty in attracting skilled and experienced workers due to poor working and living conditions.  
- Information on accidents was kept confidential.  
- The belief that if regulations were followed, nothing could go wrong.  
- Poor information display. |
| Herald of Free Enterprise | 1987 | Weaknesses in management culture were in evidence in this incident. |
In November 1990, the Cullen Enquiry set up to establish the cause of the disaster, concluded that the initial condensate leak was the result of maintenance work being carried out simultaneously on a pump and related safety valve. Piper Alpha's operator, Occidental, were found guilty of having inadequate maintenance procedures.

The report drew attention to:

- failures of the Permit to Work System
- Inadequate training in the use of Permits to Work and lack of enforcement of agreed procedures.
- Poor general standards of training for emergencies.
- Lack of involvement of senior management in critical safety matters - to ensure use of agreed procedures, involvement when problems arose, planning for major emergencies etc.

The report led to extensive restructuring of the UK offshore safety legislation. Lord Cullen also recommended the introduction of the Safety Case concept for offshore safety management.

This was a classic example of failure to follow procedures, problems in management and problems in communication.

Many lessons were learnt from the incident including:

- weaknesses in warehouse design and the use of fire prevention and control systems.
- errors in documentation describing the properties of chemicals, and the safety policy was not implemented because warehouse staff were unaware of the documentation. No staff in the logistics department had chemical training.
- If adequate water retention facilities had been present by local bunding and more widely across the site, run-off would have been prevented.
- Emergency plans need provision for rapid analysis to identify plume toxicity as well as dealing with the aftermath.

The E. coli outbreaks in November 1996 in Lanarkshire and the Forth Valley claimed the lives of 20 people. The food safety proposals in the subsequent Pennington Report were accepted by the Government and included:

- New licensing arrangements for butchers’ premises.
- All food handlers to have basic food training and intermediate level training for supervisory staff.
- Separation in storage, production, sale and display, between raw meat, unwrapped cooked meat/meat products, and other ready-to-eat foods.
- The introduction of food hygiene training in primary and secondary schools.
- An education programme for farm workers.
<table>
<thead>
<tr>
<th>Incident</th>
<th>Year</th>
<th>Description</th>
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<tbody>
<tr>
<td>Channel Tunnel</td>
<td>1996</td>
<td>This incident demonstrates several issues including:</td>
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<td>• different perceptions of risk were evident in the views of drivers interviewed after the incident</td>
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<tr>
<td></td>
<td></td>
<td>• layered safety systems allow margins for safety when one layer fails</td>
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<tr>
<td></td>
<td></td>
<td>• issues relating to fire safety and to emergency planning</td>
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<td></td>
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<td>• communications failures.</td>
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<td>Paddington 1999</td>
<td>1999</td>
<td>The crash at Ladbroke Grove Junction on 5 October 1999 between trains operated by Thames Trains and First Great Western (FGW) caused</td>
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<td></td>
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<td>considerable loss of life and injuries. Failures to learn from past incidents and poor training were identified as root causes of the incident.</td>
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<tr>
<td>Concorde 2000</td>
<td>2000</td>
<td>The root cause of this incident could be attributed to</td>
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<td>• management failures at the airport in relation to runway checks that left debris on the ground,</td>
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<td>• Continental maintenance procedures that allowed a part to fall from an aircraft causing tyre damage to Concorde,</td>
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<td></td>
<td></td>
<td>• design failure in Concorde itself that allowed tyre fragments to damage fuel tanks.</td>
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**Rod Barratt** is a Chartered Chemist by profession and has spent most of his career in the teaching and practice of air quality management. In local government environmental protection and engineering consultancy he built a practical foundation in his subject. In 1987 he joined the Open University, where he is Head of the Department of Environmental and Mechanical Engineering. His teaching interests focus on air quality management and wider aspects of safety, health and environmental management.

In addition to about 40 journal publications, he has written two books dealing with environmental management, one on atmospheric dispersion modelling, and contributed chapters on energy management and environmental analysis to books and encyclopaedias.