Case Study: The Consequences of Poor Human Factors at a Supercritical Coal-Fired Power Plant

Introduction

Modern power stations employ sophisticated automation, digital control systems, and advanced protection schemes to achieve high efficiency and reliability. However, even the most technologically advanced facilities remain dependent upon the people who operate, maintain, and manage them.

This case study examines a supercritical coal-fired power plant that suffered catastrophic equipment failures despite being equipped with state-of-the-art control technology. Over several years, the plant experienced the destruction of two steam turbines and one generator, resulting in losses valued in the tens of millions of dollars and extended periods of lost generation.

Subsequent investigations concluded that the primary causes were not deficiencies in the plant's hardware, but failures in the integration of Human Factors (HF) principles throughout the design, operation, and maintenance lifecycle.

Background

The plant was commissioned as a modern supercritical coal-fired generating station designed to achieve high thermal efficiency and reliability. The facility incorporated:

- Advanced Distributed Control Systems (DCS)
- Automated protection systems
- Digital monitoring and diagnostic tools
- Modern turbine and generator technology

Despite these technological advantages, repeated major incidents occurred during operation.

Investigators found that while significant attention had been given to equipment design and performance, insufficient consideration had been given to how personnel interacted with systems, procedures, and plant equipment.

Human Factors Issues Identified

The investigation revealed several systemic weaknesses.

1. Non-Human-Centred Procedures

Operating procedures had been developed primarily from technical documentation rather than from an understanding of how operators actually performed tasks.

Problems included:

- Procedures that were difficult to follow under operational conditions
- Excessive complexity
- Poor formatting and accessibility
- Ambiguous instructions
- Lack of validation under realistic operating scenarios

As a result, personnel frequently relied on experience and informal methods rather than documented procedures.

2. Inadequate Training

Many operators and supervisors had not received sufficient practical training on the plant's actual systems and failure modes.

Training deficiencies included:

- Limited understanding of equipment interactions
- Insufficient exposure to abnormal operating conditions
- Inadequate simulator-based practice
- Poor understanding of critical protection systems

Personnel often knew how to operate the plant during normal conditions but were less prepared for abnormal or emergency situations.

3. Weak Supervisory Oversight

The investigation found inconsistent supervision of operational and maintenance activities.

Examples included:

- Limited verification of critical tasks
- Insufficient monitoring of procedural compliance
- Acceptance of informal work practices
- Failure to challenge unsafe behaviours

Over time, deviations from standard operating practices became normalized.

4. Poor Labelling and Plant Identification

Field equipment labelling and signage were found to be inadequate.

Issues included:

- Inconsistent naming conventions
- Difficult-to-read labels
- Poor visibility in operational environments
- Confusing identification of critical equipment

These conditions increased operator cognitive workload and increased the likelihood of selection errors during both routine and emergency tasks.

5. Normalisation of Deviance

One of the most significant findings was a culture in which personnel routinely operated outside documented procedures.

Common behaviours included:

- Using unofficial workarounds
- Skipping procedural steps
- Relying on memory rather than written instructions
- Informal communication of operational practices

Because these deviations often appeared successful in the short term, they gradually became accepted as normal operating practice.

Incident Timeline

Phase 1: Design and Commissioning

The plant was commissioned with advanced technical systems but without a structured Human Factors programme.

Key omissions included:

- Human-centred procedure design
- Human reliability assessment
- Ergonomic review of operations
- Formal HF risk management

Although technically capable, the plant entered service with latent organisational vulnerabilities.

Phase 2: Routine Operation

During normal operation, personnel increasingly relied on informal practices.

Indicators included:

- Frequent departures from written procedures
- Reliance on operator experience
- Variable standards between shifts
- Reduced confidence in existing documentation

These behaviours created conditions for future failures.

Phase 3: Maintenance and Repair Activities

Maintenance activities were conducted under conditions of inadequate supervision and poor task support.

Contributing factors included:

- Weak verification processes
- Inadequate task planning
- Poor equipment identification
- Limited independent checking

The probability of human error increased significantly.

Phase 4: Turbine Lubrication Oil Event

A critical event occurred involving the loss of turbine lubrication oil.

Although the exact sequence varied across investigations, evidence suggested a combination of:

- Operator error
- Procedural weaknesses
- Inadequate supervision
- Failure to recognise developing hazards

Loss of lubrication on a high-speed steam turbine can rapidly result in severe bearing damage, rotor instability, and catastrophic mechanical failure.

The turbine sustained extensive damage.

Phase 5: Repeat Equipment Failures

Despite repair and return to service, the underlying Human Factors issues remained unresolved.

Subsequent events followed similar pathways:

- Human error occurred
- Defences failed
- Organisational weaknesses remained unaddressed

The plant experienced:

- Destruction of a second turbine
- Destruction of a generator
- Additional forced outages

The incidents demonstrated that replacing equipment alone does not eliminate risk when systemic organisational issues remain.

Root Cause Analysis

Investigators concluded that the equipment failures were symptoms rather than root causes.

The true root causes included:

- Organisational Factors
- Lack of Human Factors integration
- Weak safety culture
- Inadequate management oversight
- Procedural Factors
- Poorly designed procedures
- Limited usability of documentation
- Lack of procedural validation
- Personnel Factors
- Inadequate training
- Reduced procedural compliance
- Reliance on informal practices
- Workplace Factors
- Poor labelling
- Increased cognitive workload
- Insufficient error prevention measures

The failures resulted from multiple layers of weakness aligning simultaneously rather than from a single mistake.

Consequences

The impact of the incidents was severe.

- Financial Impact
- Equipment replacement costs in the tens of millions of dollars
- Extensive repair expenditures
- Lost generation revenue
- Operational Impact
- Long-term outages
- Reduced plant availability
- Reduced reliability
- Organisational Impact
- Increased regulatory scrutiny
- Loss of stakeholder confidence
- Significant resource diversion to investigations and repairs
- Lessons for Steam and Combustion Engineers

Lesson 1: Technology Alone Does Not Ensure Safety

Advanced control systems cannot compensate for poor human-system interaction.

Safe operation requires effective integration of people, procedures, technology, and management systems.

Lesson 2: Design Procedures for Humans

Procedures should be:

- Clear
- Concise
- Easy to navigate
- Tested under realistic conditions
- Written with operator involvement

A technically correct procedure that cannot be easily used is a safety risk.

Lesson 3: Invest in Competency Development

Training should include:

- Normal operation

- Abnormal operation
- Emergency response
- Practical simulations
- Refresher training

Competence must be continuously maintained rather than assumed.

Lesson 4: Strengthen Supervisory Controls

Supervisors should:

- Verify critical tasks
- Challenge deviations
- Reinforce procedural compliance
- Promote reporting of concerns

Strong supervision provides an essential barrier against human error.

Lesson 5: Treat Deviations as Warning Signs

When personnel routinely operate outside approved procedures, organisations should investigate immediately.

Repeated workarounds often indicate deeper problems with:

- Procedure design
- Training
- Equipment design
- Organisational culture

Lesson 6: Investigate the Human Layer

Following equipment failures, investigations should examine:

- Decision-making processes
- Communication
- Training effectiveness
- Procedure quality
- Supervisory oversight
- Workplace ergonomics

Focusing only on mechanical damage may overlook the true causes of failure.

Discussion Questions

Q. Why did advanced automation fail to prevent these incidents?

Q. How can poor procedure design increase the likelihood of human error?

Q. What indicators might reveal that personnel are operating outside standard practices?

Q. How could better supervision have prevented the lubrication oil event?

Q. What Human Factors improvements would you prioritise if you were the plant manager?

Q. How can engineers ensure that lessons learned are embedded into future projects?

Conclusion

This case demonstrates that major industrial failures are often the result of organisational and human-system weaknesses rather than equipment defects alone. Despite possessing modern digital control systems and advanced technology, the plant experienced repeated catastrophic failures because Human Factors principles were not adequately integrated into design, operation, maintenance, and management processes.

For steam and combustion engineers, the key lesson is clear: reliable plant performance depends not only on the quality of equipment, but also on the effectiveness of the people, procedures, and organisational systems that support it. Human Factors must therefore be treated as a critical engineering discipline rather than an optional consideration.