Human factors aspects of remote operation in process plants

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Human factors aspects of remote operation in process plants

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Following the 1999 ‘competition of ideas’, Human Reliability Associates (HRA) was commissioned by the Health & Safety Executive (HSE) to carry out a study of human factors aspects of remote operation in process plants.

The work conducted consisted of a literature review and a survey of the current state of remote operation in process plants. The survey was conducted using a combination of self-completion questionnaires and site visits. This report defines the areas of interest, summarises the main findings of the survey, discusses the benefits and problems associated with remote operation and provides suggestions for optimising remote operations.

Many of the sites surveyed had increased, or were planning to increase, their level of remote operation. The main reasons given for these changes were to improve productivity, to satisfy regulatory requirements and to keep pace with technology. There was little hard evidence that these alterations led to improvements. The survey indicated that the introduction of remote operation has significant effects on the way work is conducted. This was particularly apparent in areas such as communication between Field Operators and Control Room Operators and information acquisition. Very few sites systematically examined and managed the impact of these changes.

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EXECUTIVE SUMMARY

Following the 1999 ‘competition of ideas’ process, Human Reliability Associates (HRA) was commissioned by the Health and Safety Executive (HSE) to carry out a study of human factors aspects of remote operation in process plants. HRA developed a proposal that consisted of two phases of work. The first phase, described in this report, was a survey of current practices in industry. The second, which has not yet been commissioned, was to involve the application of the survey results to develop a tool to assist companies introducing remote operation and to audit existing operations.

The work carried out in the first phase consisted of two separate but complementary stages: a review of literature relevant to this topic area (Annex Report 1), and a survey of the current state of remote operation in process plants based on the findings of the literature review. This report defines the area of interest, summarises the main findings of the survey, discusses the benefits and problems associated with remote operation, describes potential strategies for managing a change in remote operation and provides suggestions for optimising remote operations.

The survey, although not of sufficient scale to produce statistically significant results, was very successful at establishing trends in industry and collecting anecdotal evidence of benefits and problems. In particular it demonstrated that the vast majority of process plants surveyed were remotely operated and that many were planning, or had recently completed, further increases to the degree of remote operation at their sites. A striking finding of the survey was that the opportunity had often been taken to carry out several changes simultaneously, for example centralisation, de-manning, upgrading of control systems and increased automation.

The main reasons given for increasing the degree of remote operation were: to improve efficiency/productivity, to keep pace with technology and to satisfy regulatory requirements. The effects of these changes were wide ranging, for example, Control Room Operators were often expected to take more responsibility following an increase in remote operation. However, training provided tended to focus on the process and control system rather than on human issues such as communication and problem solving. The introduction of remote operation had significantly altered the style of communication used in most companies. Opportunities for face-to-face communication between Control Room Operators and Field Operators tended to reduce. There was a corresponding increase in radio communication. Information received from instruments had also changed, electronic displays replaced analogue and the amount of local gauges and displays reduced. Direct perception (sound, smell, sight) was not considered an important source of information. There was evidence that remote location had forced Field Operators to plan their excursions in detail.

Very few organisations surveyed could provide more than anecdotal evidence regarding improvements in safety, productivity, efficiency or quality resulting from changes to work organisation. This was surprising in view of the scale of investment that the changes required. The main benefits were seen to be in regulatory compliance and reduced manpower costs. The lack of hard evidence of benefits suggests that the effects of changes are not being closely monitored and provokes some concern about change management strategies. It must be said, however, that none of the companies implicated remote operation as a partial or main cause of a major safety incident or process upset.

To summarise, the main issues to arise from this research included the influence of remote operation upon the information acquisition of operators. However, this importance was not reflected in the understanding of the survey’s participants as very few had assessed how operators receive plant data or communicate with others. Most assessments tended to focus on the technical system (e.g. control systems) to the exclusion of human issues. Secondly, many of
the companies surveyed had carried out simultaneous changes (e.g. manning levels, process displays, level of automation) when introducing remote operation. It was not clear that these changes were being adequately managed. Finally, Control Room Operators emerged as key figures in successful remote operation. However, the depth of training provided did not reflect this significance. It is recommended that further work be conducted to ensure that companies adopting any level of remote operation are equipped to evaluate and manage socio-technical system issues related to remote operation.
1 INTRODUCTION

This project was commissioned as a result of the 1999 “competition of ideas” which identified the safety aspects of remote operation of process plant as an area where research would contribute to current knowledge. On acceptance of the original project outline Human Reliability Associates developed a proposal that consisted of two phases of work. The first phase was a survey of current practices in industry regarding remote operation of process plant. The second, which has not yet been commissioned, was the application of the survey results to develop guidelines for companies planning to introduce remote operation, which could also be used for audit and evaluation.

The first phase of this research is documented in two reports. This report is a summary of the findings of the survey conducted to establish the state of the art in the process industry with regard to remote operation. The second report consists of a literature review on the subject of remote operation of process plant. The findings of the literature review were used to develop the questions in the telephone and questionnaire survey.

1.1 WHAT IS REMOTE OPERATION?

Chemical reactions in process plants are rarely directly observed and controlled; progress is inferred by monitoring pressures and temperatures and control is mediated through computers. Therefore, most processes are controlled remotely, but to varying degrees. Remote operation is not solely determined by distance, for example, a soundproof, windowless control room is more remote than a control room, in the same location, that allows its occupants to see and hear the processes they are controlling.

Information about the process makes remote control possible, successful remote operation is determined by information quality and operator skill. Control room operators obtain information from control room panels and alarms, communication with other operators in the control room, and from written reports. They also receive information by communicating with operators in the field who use local instruments and direct perception (hearing, smelling, seeing) to establish process conditions. Remote operation occurs whenever some form of barrier exists between the process being controlled and the person controlling it. The barriers are overcome by the indirect transmission of process information.

For the purposes of this research we have considered any plant that has a control room and where two or more remotely located people perform some operational tasks. The degree of remoteness relates to factors such as the distance between the control room and the plant, the nature of interaction between the Control Room and Field Operators and the extent to which operation is automated. Over recent years advanced technology has increased the viability of remote operation in two main ways:

- In the past most control systems were pneumatic, this limited the distance from which control could be achieved. Digital control systems are not limited in this way
- Automatic control systems have become far more sophisticated. The requirement for manual intervention, especially during “normal” operation, has decreased, allowing the size of operating teams to reduce but requiring changes to the way they are organised

1.2 SOCIO-TECHNICAL SYSTEMS

Remote operation of process plants is made possible by equipment that is used to monitor and control the process. The effectiveness of this technology, however, is significantly reduced if the people in the system, including those who operate and maintain it, are unable to use it
effectively. In this context a remotely operated process is an example of a complex socio-technical system.

Defining a process plant as a socio-technical system highlights the complex interrelationship between people and technology. Every plant has a group of workers who operate the technical component within an organisational and management infrastructure. Furthermore, every plant operates under the influences of external stakeholders (for example regulators, competitors, shareholders and the head office) who influence the management of the plant. Examining remote operation within a socio-technical context promotes consideration of these interrelationships, how they change as control becomes more remote and the potential effects of these changes on safety and efficiency.
2 REVIEW OF REMOTE OPERATION OF PROCESS PLANT

2.1 WHAT IS HAPPENING IN THE PROCESS INDUSTRY?

The first objective of the survey was to establish the degree to which the operation of process plants is becoming more remote. The vast majority of plants surveyed were operated remotely to some extent. The few that were not were relatively small, manually operated processes, run by a single person using local control panels.

Table 1

<table>
<thead>
<tr>
<th>Types of remote operation in process plants surveyed</th>
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</thead>
<tbody>
<tr>
<td>Non-remote operated plants</td>
<td>19%</td>
</tr>
<tr>
<td>Remote operation with no planned change</td>
<td>7%</td>
</tr>
<tr>
<td>Recent change to degree of remote operation</td>
<td>60%</td>
</tr>
<tr>
<td>Planned change in near future</td>
<td>13%</td>
</tr>
</tbody>
</table>

2.2 CLASSIFYING ELEMENTS OF REMOTE OPERATION

All remotely operated plants have a control centre of some description, and are operated by more than one person for some of the time. However, there is considerable variation in how this is achieved. The main options include:

- Operating team based in the control room. Field Operators periodically visit the plant to carry out status checks and other tasks.
- Field operators based on the plant, working in the same team as Control Room Operators. They periodically visit the control room.
- Teams divided into field and control room operation. Field Operators rarely visit the control room.
- The plant is operated from another site. The plant is unmanned for some of the time it operates.

In the survey 37% of control rooms were not permanently manned. 63% involved some element of batch processing, allowing the Control Room Operator to take breaks during “quiet” process periods. In 90% of these cases the control room was left unattended whilst the operator visited the plant to perform process activities. This excluded the 23% of processes surveyed that did not have dedicated Control Room Operators.

Despite the advanced technology available, and the “theoretical” feasibility of unmanned operation, Field Operators were still apparent at the plants surveyed. In every organisation surveyed there were at least as many Field Operators as Control Room Operators, in some cases four times as many.

69% of the plants had a supervisor. 5% had adopted the self-managed team approach with one of the operating team acting as team leader.

2.3 IMPLEMENTATION OF REMOTE OPERATION

Many process plants have a history of remote operation. However, the survey results demonstrated that a large number of companies have increased, or are planning to increase, the level of remote operation at their sites. In most cases, several changes occurred concurrently, for example, movement to a central control room was accompanied by a new control system. This is probably because it is easier to financially justify several changes in a single project, than phased changes over a longer period. Change presents opportunities, but it is easy to make
more changes than can be safely managed. Moreover, from the perspective of this project it is
difficult to assign the benefits and problems to one alteration where several have occurred
concurrently.

<table>
<thead>
<tr>
<th>Table 2</th>
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<tbody>
<tr>
<td><strong>Changes recently completed or planned</strong></td>
</tr>
<tr>
<td>No change</td>
</tr>
<tr>
<td>Move to a central control room</td>
</tr>
<tr>
<td>Increased automation</td>
</tr>
<tr>
<td>Reduction in operating team</td>
</tr>
<tr>
<td>Move control room further from plant</td>
</tr>
<tr>
<td>Move control room closer to plant</td>
</tr>
<tr>
<td>Upgrade existing control system</td>
</tr>
</tbody>
</table>

Most reasons given by participants, for changing the level of remote operation, could be split
into three broad categories. The most common was cost, improving efficiency, increasing
production and reducing costs. The next was to keep pace with control room technology.
Finally, some sites were responding to guidelines and legislation, such as occupied buildings
regulations. Specific reasons given included:

- Obsolescence of control technology and availability of spares
- Y2K compliance
- To improve the user interface
- Use of more reliable digital instruments and controllers, when compared to existing
  pneumatic systems
- Increased automation to improve throughput, product quality and consistency
- Ability to make new products with tighter specifications
- Maintaining throughput with less people
- Building new plants without needing more people to operate them
- To reduce manual handling
- Moving control rooms away from danger zones
- Moving more processes into the same control room so that communication between
  personnel on different plants would improve

During the survey it became apparent that every organisation viewed change differently, this
influenced the management of these changes. In some cases, changes were seen as
instrumentation upgrades and instrument engineers ran the project. Others saw it as a process
operations improvement and consequently it was managed by members of the operating team
(typically senior supervisor or operations manager). In other cases it was seen as an
organisational change, and managed by business managers.

2.4 WHY AREN’T ALL PLANTS OPERATED REMOTELY?

Not every company was moving towards high levels of remote control, typified by centralised
computer control. Cost was one reason for this but other explanations were given. For
example, where minimum manning had been achieved with an existing system the main benefit
of installing more advanced systems would be to adopt some level of unmanned operation. One
company had decided that this was not suitable for a major accident hazard site. By contrast, a
larger company with a predominantly mechanical manufacturing process, involving a large
amount of manual intervention, felt that automation of the existing plant was too complicated to
attempt. Finally, a company manufacturing a particularly hazardous product were forced to
work to product quotas; hence there was no incentive to increase production or the economy of
scale to justify more advanced control.
2.5 OPERATING REMOTELY

There was fairly unanimous agreement that increasing levels of remote operation place more reliance on the skill and ability of Control Room Operators. In 33% of cases dedicated Control Room Operators were used. In the remainder, operators rotated through both field and control room operation. The main advantage of rotation is the flexibility it provides in covering absence from work and shift breaks. In most cases, however, the operating teams arranged this rotation informally. If the Control Room Operator is as critical as most perceive then this would be one area where greater management would be expected. Some companies recognised that too much time spent operating from the control room may result in a loss of “feel” for plant operation. They managed this by scheduling shifts (for example one per month) where the Control Room Operator works in the field. Such an approach requires careful management to avoid problems with inexperienced operators in critical areas.

For companies that have “continental” shift patterns, which include extended breaks (typically 18 days) throughout the year, team strength should remain fairly consistent. Where shift patterns do not include extended breaks, holidays and other absences are covered by operators “swapping” shifts with their colleagues. During school holidays this may create difficulties in maintaining a balance of experience in all jobs. The downside of the continental pattern is that after an extended break the whole shift return to work at the same time and all will be unfamiliar with events or changes that have occurred during their absence.

The literature on Control Room Operator training suggests that “higher level” skills are important. However, only 3% of the participants referred to the provision of problem solving, 3% to communication and 5% to leadership training. The majority of training reported focused on the process and control system, and was typically covered on-the-job. Only 23% of participants specifically referred to emergency training, 3% of which used a simulator. Over reliance on on-the-job training can cause bad habits to be passed on and reinforced. In addition, it is an unreliable method of training for low frequency task such as emergency response.

15% of participants reported that the adequacy of Control Room Operator training was assessed before individuals were allowed control of the job. 5% used the NVQ to set the standard. Only 15% referred to any form of refresher training.

2.6 COMMUNICATION

Communication is critical because remote operation typically involves collaboration between at least two people. Usually one person is based in the control room and the others on the plant. The questionnaire sought to establish variations in communication types used in different forms of remote operation. Many participants found this difficult to estimate with any accuracy. This suggests that most companies have not formally analysed this critical aspect of operation, which in turn raises issues about how change can be successfully managed if the current situation is not fully understood.

The most obvious, and effective, method of communication is face-to-face. On process plants most face-to-face communication occurs in the control room, therefore the amount of time operators spend here is a key indicator of the amount of face-to-face communication that takes place. The participant’s estimates showed great variation from no opportunity to communicate face-to-face on some plants, to others where it accounted for 90% of communication. On average increased remoteness of operation resulted in a 40% drop in the level of face-to-face communication.

Several participants commented that face-to-face was the most effective method of communication. Their comments included: “it is easier to convey urgency and hence problems
are identified more quickly”, “things get done better” and “you are more likely to get the correct interpretation of the message”. Moving the control room further from the plant reduces the amount of face-to-face communication between Control Room and Field Operators. Where centralisation occurs, opportunities for face-to-face communication between Control Room Operators from different units may increase. Several companies have commented that they expect this cross-unit communication to be particularly beneficial in improving overall site efficiency. However, so little analysis is generally carried of communication it is difficult to see how any company can be sure that the benefits of cross-unit communication will outweigh the losses that may occur due to reduced face-to-face communication between the Control Room and Field Operators.

The second most common method of communication was the use of radios. This accounted for 28% of communication. In most cases these consist of open frequency broadcasts, which results in groups of people hearing the same messages. At least one company used a “trunked” radio system, allowing messages to be passed to individuals or differing groups. If the operators use this feature correctly the level of distraction should decrease. Some companies have started issuing mobile phones to members of their operating teams, this accounted for 4% of communication. Finally, 15% of communication involved fixed telephones and 8% tannoy systems.

Several participants reported the use of written communication, 9% using paper and 11% email. One company used a PLC based text system where non-urgent messages could be left for Field Operators, to be picked up at their convenience.

Arguably the most critical form of communication that takes place is not between different people on the same team, but between different teams at shift handover. 23% of participants reported making recent changes to improve the quality of shift handover. The main changes were to formally include handover time as part of the shift, to vary the handover depending on the length of absence, and to improve written logs. The benefits reported included reduced downtime, increased knowledge of operations and better consistency across shift changes.

2.7 RECEIVING PLANT INFORMATION

The survey results indicated that where remote operation increased a greater proportion of process information was displayed in electronic rather than analogue form. In addition, there was a reduction in the use of local displays and gauges. Participants were asked how much process information operators receive via direct perception such as hearing, smelling and feeling. A reduction would have been expected. However, this is not generally considered a significant route by which plant information is received, and hence increased remoteness did not appear to alter the amount of this information used. It is possible that the role of direct perception is significantly underestimated, particularly for detecting fault conditions. If this is the case there is a real danger that remote operation will have an adverse affect on plant safety. Some operators, however, pointed out that moving them further from the plant forces them to be more aware of what is happening. In the past they would have simply “popped-out” to carry out a task and then returned to the control room. As this is no longer possible they take a more systematic approach and spend more time on the plant with each visit. If the early signs of potential problems are spotted intervention may occur sooner than in the past.
3 BENEFITS AND PROBLEMS OF REMOTE OPERATION

Any system change has potential benefits and problems. This table summarises some potential issues caused by a change to remote operation. Some more detailed examples from the survey are described below.

<table>
<thead>
<tr>
<th>Change</th>
<th>Potential Benefits</th>
<th>Potential Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced manning levels</td>
<td>Reduced costs</td>
<td>Increased work load, difficulty in covering sickness and absence, stress</td>
</tr>
<tr>
<td>Digital control systems</td>
<td>Cheaper to maintain, more reliable</td>
<td>Problems during power failure</td>
</tr>
<tr>
<td>Computer interface to control system</td>
<td>Data more readily available allowing early detection of problems</td>
<td>Information overload for operators, additional skill to learn in using interface, belief that the system has become more reliable when only the interface has improved</td>
</tr>
<tr>
<td>Increased automation</td>
<td>Improved consistency, reduced workload</td>
<td>Over-reliance resulting in reduced vigilance, boredom</td>
</tr>
<tr>
<td>Control room further from plant</td>
<td>People removed from dangerous areas</td>
<td>Reduced opportunities for personal contact and face-to-face communication</td>
</tr>
<tr>
<td>Use of radios</td>
<td>Easier to contact people on the plant</td>
<td>Problems during power failure, technical reliability of radios</td>
</tr>
</tbody>
</table>

3.1 EXAMPLES OF BENEFITS OF REMOTE OPERATION

Despite the large investment required to implement remote operation, the participants described very few formal improvements in terms of production, reliability or quality. Most of the reported benefits were in terms of regulatory compliance and reduced manpower. One reason for failing to identify specific benefits is that often multiple, simultaneous changes are made to the way the plant is operated making it difficult to assign benefits to one area of change.

The following examples illustrate the types of benefits reported during the survey:

**Example 1:** Reduced costs were achieved by reducing the size of an operating team by 40%. Multi-skilling was adopted to ensure that de-manning occurred without an adverse affect upon operation

**Example 2:** A quicker response to equipment breakdowns was achieved by adopting a number of technological advances. These included a modern control system, increased automation and a computer based maintenance request system. These advances allowed the operation of several plants to be amalgamated and the control room to be moved to a more convenient location. In addition multi-skilling was adopted and the size of the operating team reduced by 25%. An additional, informal benefit was that operators felt more in control of the plant

**Example 3:** Improved plant equipment reliability was achieved by installing a new control system with automatic sequence control and a new user interface. This allowed extra processes to be controlled without an increase in the size of the operating team. The new system made analysis of operation easier, and the operators better understood the control system. The control
room was also refurbished improving the working environment, which had been further enhanced by improved alarm management

**Example 4:** Improved safety performance and reliability of plant equipment had been achieved by moving two control rooms in the plant area to a single control room outside the plant. A new DCS control system was also installed as part of the move, resulting in process information being presented on VDU screens rather than analogue panels. The move was used as an opportunity to introduce team working and multi-skilling. The shift pattern also changed, at the request of the operators. The company reported that all of these changes have contributed to an improved, open communication culture. In particular, formalised shift handovers and an increased amount of written communication, including operator logbooks, had been seen as a significant improvement

**Example 5:** Significant reduction in costs was achieved by reducing the number of operators per shift by around 40%, without any detriment to plant performance. An updated DCS system was installed but this made little difference to plant operations. The most significant changes were in the way operating teams were organised to compensate for less people. In particular the amount of multi-skilling was reduced with operators no longer performing maintenance. Shift handovers were formalised and changes made to the way absence was covered

**Example 6:** One Company had made arrangements for a range of communication methods to be used. The majority was still face-to-face, but this was supplemented by radios. They had found benefit in having a relatively high proportion of written communication. In particular, a plant status board gave a quick and easy overview of activities, helping communication

**Example 7:** Safety improved by moving to a central control room and replacing analogue panels with a computer control system. This allowed more processes to be controlled, but required a 25% increase in the size of the operating team. Organisational changes had also taken place. In particular, the shift pattern changed from 8 hours to 12 hours to reduce the number of handovers required and to make training organisation easier. More emphasis had been placed on the shift handover by allocating time for it. Incidents occurring worldwide were highlighted as the driving force behind the change

**Example 8:** Changes to improve quality resulted in improved safety performance. Prior to the change, control was achieved via local control panels and gauges. Most of this was replaced with a computer control system with full automation for the blending process. This resulted in a 40% decrease in the size of the operating team. Working arrangements have been made to counteract this downsizing, including team working, multi-skilling and empowerment. The shift pattern also changed to include 18-day breaks that ensured consistent make-up of operating teams

**Example 9:** Communication improved by developing Control Room and Field Operator roles. In the past an operator could perform more tasks alone. Two operators working together, communicating using radios now perform more tasks

### 3.2 PROBLEMS EXPERIENCED WITH REMOTE OPERATION

None of the companies surveyed implicated remote operation as a cause in disasters. However, several did experience problems, the following examples illustrate some of these issues:

**Example 1:** One Company that had made multiple changes to the control room and organisation experienced significant fear of change from the operators. A communication exercise was conducted and thorough training on all the new control systems provided, this helped the operators appreciate the benefits of the change
Example 2: A lack of operator familiarity with a new control system, in particular alarms and trips, caused significant problems at one site. The changes occurred at the same time as a major plant commissioning. With hindsight, this combination was felt over ambitious and caused a great deal of confusion and stress. Over time the operators have become familiar with the new system. What was not anticipated, however, was that extra resources from day staff were required to manage aspects of operation that the operators would have previously carried out themselves.

Example 3: Two companies that started to use more written communication found that this lacked the quality they required. In particular, brief notes were often written, where a more detailed description of events was necessary, and ambiguous words were used that lead to misunderstandings. One of the companies responded by providing extra training in written communication to try to overcome the problem.

Example 4: The increased use of email had had an adverse affect on communication at one company. In particular technical staff were now less inclined to make personal contact with the operating teams. They have responded by emphasising the role of the Shift Supervisor, as the main contact with the operating team. Technical staff meet with the Supervisor, who relays the information to the appropriate members of the team.

Example 5: For one company, changes to the organisation of the operating teams created difficulties with sickness cover. The main problem was that with less people on each shift there was reduced flexibility for providing cover, and everyone had to be on call for a greater proportion of their breaks. Operators voiced their concern about this at the time the changes were planned, but management underestimated the importance of this issue.

Example 6: One Company had found that increased reliance on radios for communication caused major problems during power cuts. Many companies also reported problems with radios during normal conditions. In particular radios do not work in all plant areas and use of ear protection creates further hearing difficulty.

Example 7: One of the Companies that had expanded the number of processes, identified that management of the operating team had become far more critical. With more work areas, operating teams did not always have a broad enough experience base to consistently cover every work area.

Example 8: The increased use of computer and automatic control has resulted in more reliance on the engineers who maintain the systems. In the past the instruments were simple and easy to understand. Although the process itself has not changed, the DCS system is more powerful but also more complex. One company had not considered this effect fully. They had trained operators in using the new system but not trained their engineers.

Example 9: The combination of increased automation de-manning had led to increased stress levels at one organisation.

Example 10: New automatic safety systems resulted in over reliance at one plant. The operators believed the control system would protect them. In one case an automatic system had activated, without being noticed, and resulted in a drum filling with liquid. Some days later the full drum was discovered but the contents had solidified.

Example 11: A new control system was installed to manage a new process and an extra person was added to each operating team. Management concentrated on production issues surrounding the new product and had not appreciated the impact of installing the new control system. Insufficient training had been provided for operating the system.
4 MANAGING THE IMPLEMENTATION OF REMOTE OPERATION

This research was aimed at establishing current practice with regard to remote operation. Recommendations of best practice and tools and techniques were outside the research scope. The results of the survey do, however, give some insight into issues to be managed and provide pointers for change management.

4.1 PRINCIPLES OF MANAGEMENT OF CHANGE

This survey has suggested that most companies planning to implement remote operations are not clear regarding the benefits they expect. Those who have already implemented remote operation appear unable to identify significant benefits attributable to the changes. If the cliché “you can only manage what you can measure” is true then it appears that many companies are failing to manage all the changes that occur when they implement remote operations.

Ken Eason of Loughborough University, in his book “Information and Technology and Organisational Change\(^1\),” points out that because all technical innovation includes an element of risk, some projects will end in “disaster.” Although this is likely to be a small proportion he suggests that disappointment and frustration, staff resistance, problems with health and safety and damaged relationships with customers are far more common than people realise. These failures need to be dealt with; this requires time and resources and negates some of the benefits.

Eason defines the success of technological change as an organisation becoming “more effective at achieving its objective.” For any commercial organisation the main objective is to increase profit, hence technical improvements to operations, such as optimisation, improved reliability, and improved consistency are only effective if the improvement is significantly larger than the cost of the change. The fact that most organisations surveyed are unable to point to such benefits does seem to suggest that cost-benefit relationship of changes occurring during implementation of remote operation is not always being managed effectively.

4.2 ASSESSING THE COST-BENEFIT OF REMOTE OPERATION

In any commercial organisation a project with a cost has to be justified by changes with a benefit. The stakeholders need to be sure that the project represents value for money. Typically, this means that production will increase to cover the costs of the project in a reasonable time, or that the improvements to safety or environmental performance are necessary and likely to be effective. It is important to remember, however, that remotely operated process plants are complex socio-technical systems. It cannot be assumed that the use of advanced technology, for example a sophisticated control system, will automatically achieve benefits if the potential cost-benefits to users of the system are not considered.

The chances of successfully balancing benefits and costs increase if the users gain personally by the change. In this context benefits include making the job more interesting and pleasant, improving salaries, increasing power and influence of the individual and improving career prospects. Costs, on the other hand, are not just the financial impact to the individual but also loss of job security, loss of job satisfaction, fear of change and having to learn new methods and adapt to new systems.

Two of the survey participants mentioned the failure of past projects. In both cases the failures involved the installation of computers intended to improve monitoring and increase automation.

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in an existing control system. They failed because they were not powerful enough to deal with the complexity of the processes they controlled. The survey results indicate that in the past change was relatively “evolutionary.” The failures described above did not stop the plant producing or cause accidents. The power of new technology is in allowing more “revolutionary” changes to take place, as highlighted by the number of plants taking on multiple, parallel changes whilst increasing the level of remote operation.

Most participants planning changes recognised the likelihood of a significant impact on the system users. Few, however, are planning to do much to manage this beyond training people to use the new technology. In addition, those who had made changes had not recognised particular problems.

Remote operation tends to increase distance between, and reduce opportunities for interaction between Control Room and Field Operators. However, in most cases they will have worked together for some time before being separated. They will undoubtedly retain an understanding of each other’s tasks and responsibilities, even without regular face-to-face contact for reinforcement. However, over time, without the opportunity to interact, that relationship will decline, especially as new operators will join who were not parts of the original team. These workers will not have the same opportunities as their predecessors to develop close working relationships. By recognising this likelihood organisations can reduce the impact of this change. This could be done by rotating workers through different jobs, and encouraging interaction between work groups.

4.3 POTENTIAL IMPACT OF IMPLEMENTING REMOTE OPERATION

We have reviewed the findings from the questionnaire survey and case studies to develop a list of issues to consider when implementing, or increasing the level of, remote operation. Where any of the issues listed are relevant they should be part of the change management process. As this survey has identified, most plants change many of the elements of operation in a relatively short time, requiring an effective management of change process.

4.3.1 Moving the point of control further from the plant

Moving the location of a control room has an immediate impact on the operators’ relationship with plant. It may also affect their relationship with each other. The issues to consider include:

- Field and Control Room Operators may have less opportunity for face-to-face communication
- Basing Field Operators in the control room may mean they spend more time away from the plant
- Providing Field Operators with a building near the plant and away from control room may adversely affect team work
- Control room operators will not be able to “pop onto the plant” to perform quick actions, such as reset local trips or start/stop equipment
- Technical experts may be less likely to visit the plant, as the control room becomes the focal point for most operations. They will be less likely to pick up housekeeping and other general condition of plant issues
- Greater consideration needs to be given to shift handovers, especially if the Field and Control Room Operators are based in different locations
- Putting more than one team into a control room does not automatically mean communication between them will improve. If this is an intention it needs to be managed
- Being further away from a process will mean increased response times in operators getting to equipment that is starting to run poorly
4.3.2 Using radios or mobile phone

Remote operation inevitably involves some tasks, which in the past may have been performed by one person, that now have to be performed by a Field and Control Room Operator working together. To ensure these tasks are carried out effectively the two operators need to be able to talk. Radios or mobile phones are one solution. When providing this equipment the issues to consider include:

- Effective communication using radios needs to be learnt
- It may take some time for the routine of carrying, using and maintaining (for example charging batteries) to become established
- Most plants have problems with areas of poor reception
- Use of PPE (particularly hearing protection and breathing apparatus) makes it difficult to use radios and mobile phones
- A single radio channel can be used by more than one person, creating the possibility for confusion about who messages are meant for
- A message sent via a mobile phone can only be heard by one person, hence it will take longer to transmit the same message to more than one person (for example informing them of an emergency situation)
- They must be intrinsically safe, and this means they are expensive

4.3.3 Replacing analogue with VDU control panels

The development of digital control systems has allowed more use of remote operation and reduced the importance of distance. The issues to consider include:

- With an analogue panel all the information available in the control room is visible at all times. With VDU screens more information may be available but less is visible at a given moment
- The operator may lose some spatial awareness of the panel as everything is shown on the same screens
- There is a tendency to overload the operator with alarms
- There is a greater reliance on the operator’s ability to use the interface, this is an additional skill that must be learnt and practised
- Plant managers may be less likely to talk to operators if process information is available on their desktop via local computer networks
- If instruments and controllers on the plant are not upgraded with the control system itself there is unlikely to be any significant improvement in plant reliability
- A more modern interface may lead people to believe the control system is more sophisticated or reliable. This is not necessarily the case
- “Analysis paralysis” may take over. The increased amount of data and ability to store trends can result in excessive time and resource spent analysing plant operations rather than the benefit that this can produce

4.3.4 Increasing automation

Installation of advanced control systems allows more automatic operation. In many cases this is the main justification for a new system, as it is expected to allow downsizing or to improve productivity. There are, however, some potential problems with increased automation. The issues to consider include:

- Reduced operator intervention may result in skill degradation
- Reduced operator workload may lead to boredom. Other activities (job related such as issuing permits, or non-job related such as reading the paper) may be performed that cause distractions
- If increased automation is used to reduce the size of the operating team, the reliability of the system becomes more critical as there will not be enough people to continue production on manual control
- If the operators do not understand how the automatic system functions or appreciate the benefits it is unlikely to be used as intended
- Operators can over rely on automatic protection devices, assuming these to be more reliable than they actually are
- Increased throughput achieved through increased automation can require more people, for example to package the products

4.3.5 Downsizing operating teams

Downsizing is often a consequence of other aspects of remote operation. It can make operation even more remote for individuals as it changes the relationship between the plant and operators. The issues to consider include:

- Dilution of job knowledge as areas of responsibility are enlarged
- There may be a greater likelihood of operators specialising in either field or control room operation, possibly reducing shared awareness of the other jobs. This might influence communication and teamwork
- Difficulty in covering non-process aspects of job, such as issuing permits and dealing with emergencies
- Removing the Supervisor, or spreading their responsibility over more plants, reduces the independence of monitoring of activities and may result in more violations
- Non-hierarchical teams usually result in the Control Room Operator taking a senior role by default, which may cause resentment if they do not perceive they are rewarded for the extra responsibility
- Field Operators may feel that their job has been downgraded. They may fear about their job security or opportunities for career development
- Changes to shift patterns to allow downsizing may involve longer absences (for example scheduled 18 day breaks). Shift handover will need to improve to ensure people are brought up to speed effectively on their first day back
- Operators that specialise in control room operations may start to lose their process knowledge over time, or because they have never performed the Field Operator job
- There may be difficulty to get people to cover absence
- It may become difficult for operators to have reasonable breaks during the working day
- Less people are likely to be on the plant at any given time. This may increase the time it takes to detect and respond to problems

4.4 SUGGESTIONS FOR MANAGING CHANGE

The main process of managing any change has the following stages:

- Assess how the current system works
- Identify potential improvements (financial, safety, environmental)
- Assess the cost-benefit of the changes to the socio-technical system
- Implement the changes
- Assess the effective of the changes
This process is not specific to remote operations, but the survey has revealed some issues that are particularly relevant. In particular the way the current system works needs careful attention.

One company that had installed a new control system found that the existing system did not work as intended. If they had designed the new system based on the documentation for the existing system they may have experienced some significant problems. This highlights the importance of examining actual plant data and involving the operators in the assessment of the current system before designing a new system.

The survey identified that very few companies use systematic processes for establishing user interaction with existing systems. From a human factors perspective some form of task analysis is essential prior to a change. As with the technical aspects, this analysis must be reality based, written operating procedures alone are unlikely to provide enough accurate information. For example if the Control Room Operators occasionally assist the Field Operators on the plant, to stop a piece of equipment or reset a trip, and this has not been formally recognised, problems are likely to occur if the control room is being moved. The importance of involving the system users in the change process cannot be stressed enough, but is particularly essential in establishing current practices. Once this involvement is achieved, a further challenge is to ensure that the truth is being shared. An open and honest culture will make this sharing more likely, highlighting the importance of a socio-technical consideration of process operations.

Identifying opportunities for improvement is closely related to the assessment of the current system operation. If the current system is not fully understood it will be difficult to establish the causes of problems and changes are less likely to have the required impact. One participant explained that an automated system was being installed to improve consistency within a process. However, the participant was unable to explain why the process was currently inconsistent. The assumption was that the operators were not always able to pay full attention to the process and that the automation would reduce the need for this. Whilst this assumption was probably correct, the lack of a full understanding of the causes meant that the planned improvement was a gamble.

There are two main implementation strategies, gradual alteration or rapid change. Gradual change allows production to continue and gives people the chance to get used to one thing at a time, but often requires two systems to be working in parallel requiring extra manpower and potentially causing confusion. The quick approach avoids confusion and allows everyone to be prepared for the change, but often requires the process to stop and makes little allowance for teething problems. Several participants suggested a combination of the two approaches to be the best solution. For example, start implementing changes gradually providing opportunity for familiarisation at a time when errors are likely to have a minor affect. Once the number of changes starts to cause confusion it is probably safer to shutdown, make all the changes and then re-commission.

Several of the survey participants commented that they would have liked project teams to stay with the plant for longer periods after commissioning. They felt that these people had a much clearer idea of the implementation and related alterations. This knowledge is particularly useful for dealing with teething problems.

4.5 SUGGESTIONS FOR OPTIMISING REMOTE OPERATIONS

The survey has identified specific measures that could be used to optimise the implementation of remote operation.

- Separating Field and Control Room operators can actually improve teamwork. Whereas in the past individuals could perform most of their activities alone, restrictions in movement require teamwork and effective communication
Basing Field Operators away from the plant can improve their effectiveness. In the past they would have “popped out” to do a job. This is no longer possible, but means that Field Operators need to be more systematic in their approach.

Reductions in shift manpower can be managed by modest increases in day staff. If well organised, the bulk of non-process activities (for example permit-to-work, scheduling) can be removed from the operating team’s agenda, reducing distractions.

Installing CCTV can improve safety, particularly during emergencies as the plant can be monitored without putting people in danger.

A central control room can act as a useful focal point for whole operating team communication, whereas previously they may have been based in several buildings local to individual plants.

Use of radios or mobile phones can make it easier to contact staff, if they are carried and switched on.

Installing computers in control rooms allows the use of computerised log books and maintenance requests which can improve monitoring of plant activities.

Providing a method of leaving non-urgent messages for Field Operators, such as a text display on the plant or email to a computer located in a satellite building, can ensure messages are not missed or forgotten if received during periods of high activity.

Equipment status boards can help Control Room Operators decide upon appropriate courses of action, particularly during plant disturbances.

A flip chart in the control room can be used to record the priorities of the day so that everyone is aware of them. One plant had a pro-forma chart printed to record key plant data for the last 24 hours. The morning production meeting was conducted in the control room using this information and the chart was used to record actions. Meeting minutes were not necessary and responsibility was clearly allocated.

It was generally felt that certain people have an aptitude for Control Room operations, and others do not. Before implementing remote operation it is important to identify that aptitude in the workforce. There may be a need to recruit new operators as part of the implementation.

Modern control systems are able to display and store more process information, which can also be displayed as trends or downloaded into spreadsheets for analysis. Training in the interface and encouraging people to use this information can significantly improve their ability to recognise, diagnose and respond to problems.

Change is often viewed with suspicion. However, it can be a motivator if it is viewed as confirmation that the plant has a future and the company is investing in their jobs. Worker involvement in all project stages can help foster this view. Changes are seen as a longer term development, rather than a sudden change.

One company mocked up their intended design for the control room. They arranged cardboard boxes on tables to represent the DCS control screens. The operators were asked to simulate the job their interaction with the equipment was monitored. This exercise resulted in changes to the plan, and improved operator understanding of the planned changes.
5. REVIEWING EFFECTIVENESS OF REMOTE OPERATION

For plants that have already moved towards remote operation, or have always been operated that way, the effectiveness of operation still needs to be considered. Once again the scope of this project did not include the development of a comprehensive monitoring or audit process, but the survey has highlighted a number of issues that may guide such a review.

- Are the operators over reliant on automatic protection devices? Do they pay enough attention to critical parameters or are they concentrating on other parts of the plant, happy in the knowledge that the system will “fail safe” if anything goes wrong?
- Are automatic controllers and optimisers being used? If not, why not? Is it because they do not work, or because the operators do not understand why they need to be used?
- Are automatic sequences being overridden or manually adjusted? Is this because there are errors in the sequence or because the operators do not trust the system and feel that manual operation is more reliable?
- Where are the Field Operators spending most of their time? Are they spending enough time on the plant to have a good chance of detecting problems? If they are rarely in the control room are they easy to contact when required?
- How well do the operators understand each other’s roles and responsibilities?
- Are operators spending enough time on each of their jobs to maintain competence?
- How much time do managers spend on the plant and in the control room? Does the availability of process data in the offices mean they speak to the operators less often? This may result in managers being less likely to pick up problems experienced by operators
- Are the control room operators actively monitoring the plant and dealing with minor problems? Are they relying on the alarms instead? Is this because the user interface does not allow effective monitoring, is it because the operators do not have sufficient process knowledge, or is it because they believe that is how control operator jobs are supposed to be run?
- How is operator absence covered? Is there a system for ensuring that teams are always at full strength?
- Are the operators able to assess and solve problems effectively? Do they tend to freeze at the sign of trouble or overreact?
6. CONCLUSIONS

The vast majority of process plants are remotely controlled to some degree. The introduction of
digital control systems has made remote operation increasingly feasible. Unmanned operation
is now technically possible, although in practice it is currently limited to a small number of
particularly simple and/or non-hazardous processes. It may be some time before unmanned
operation becomes common but this survey has highlighted a clear trend towards increasingly
remote operation. On larger sites this trend has manifested itself in the construction of central
control rooms.

The complex socio-technical nature of process plants means that although remote operation is
technically feasible, success will ultimately be determined by the people operating the plant and
organisational context. It is of some concern; therefore, that several of the sites surveyed were
not managing the implementation of remote operation with this in mind. In addition, in many of
the companies surveyed the implementation of remote operation involved concurrent changes to
several aspects of operation (e.g. manning levels, process displays, level of automation). The
impact of the changes on the whole system should be considered alongside technical aspects,
which the survey suggests get the most attention.

According to the definition used during this research, remote operation relies upon successful
transmission of information to operators. Two of the most important sources of information
identified by this research were indirectly presented plant data and communication between
workers. Most participants in the survey, when asked to estimate the amount of plant data
collected from various sources, for example local gauges and control room panels, found it
difficult to provide an answer. Managing any change that affects these sources of data is
difficult if their relative importance is not understood.

The key person in any remotely operated plant is the Control Room Operator. Their skill and
ability can have a major influence on the efficiency and safety of operation. The survey
identified that most Control Room Operators receive very little structured training in subjects
such problem solving and faultfinding, communication and emergency response. The majority
of skill acquisition seems to come from working alongside more experienced operators.

6.1 RECOMMENDATIONS FOR FURTHER WORK

This research project was proposed in two phases. The survey described in this report and the
accompanying literature search was Phase 1. Phase 2 was to involve development of tools and
techniques, based on the findings of Phase 1.

The survey has identified two key aspects of remote operation that are not being considered in
sufficient detail, sources of plant data and communication. It is recommended that the focus of
Phase 2 of this work should concentrate on developing new, or adapting existing, tools and
techniques to address these issues. The case studies obtained in this survey provide useful
starting points for the development of these tools and techniques.

The survey has also identified that companies do not appear to have methods that allow them to
identify specific benefits or problems resulting from the implementation of remote operation.
To ensure the benefits to safety are being maximised a method is required that gives “leading”
indicators of safety performance, so that any problems introduced can be dealt with before
incidents occur (i.e. before the “lagging” indicators start to show up).

Finally, training for Control Room Operators in higher-level skills, such as problem solving has
emerged as a significant issue. Although these skills are also of relevance to Field Operators,
the key role of the Control Room Operator in remote operation means that more guidance is required for companies when developing their training plans and assessing individuals.

6.2 OPPORTUNITIES FOR FURTHER WORK

It is clear that practical tools and techniques are required to tackle these issues. The tools must be usable by site teams with minimal input from human factors specialists. In order to ensure this, it is essential that the work in Phase 2 of this project be conducted in close collaboration with actual plants. Some reluctance was encountered during this survey for company employees to allocate time to this type of research. However, a number of the participants planning significant changes indicated that, given suitable motivation, they would be interested in testing tools that may be of benefit to them. In particular several central control rooms are being planned. These would present ideal opportunities as they represent the most significant implementation of remote operation that most plants would ever achieve.
APPENDIX 1 – QUESTIONNAIRE SURVEY DEVELOPMENT

This project was commissioned to evaluate the current state of the art in terms of the introduction of remote operation into process plants. The key objective was to survey current practices in industry in order to evaluate the value of developing guidelines, audit and evaluation tools (phase 2 of the research which has not yet been commissioned). A questionnaire survey was identified as the most effective means of achieving this.

SURVEY PHILOSOPHY

The purpose of the survey was to establish whether the human factors issues identified in the literature review (see separate report) were recognised by the people involved in establishing, operating and managing remotely operated process plants, and the level of significance these factors have for safety. The literature review had indicated that the concept of ‘remote operation’ is relatively abstract and is closely associated with other issues such as de-manning, increased automation, centralisation, etc. The survey was arranged to so that all the main issues could be assessed, rather than concentrating on those specifically related to remoteness of operation, as it was likely to have different meanings to different participants.

TELEPHONE SURVEY

The first phase of the survey was based on a brief set of questions designed to establish the general trends regarding remote operations. The issues that were considered were explained to the participant and they were asked to focus on one particular part of their plant (e.g. a process unit) that they felt was most relevant to the survey. They were then asked to explain the status of remote operation in that plant area, had they made significant changes within the last 5 years, were they planning to, or was the status relatively static? As well establishing the state of the art, the answers to this question determined which questionnaire the participant would receive if they agreed to take part in the questionnaire survey.

The participants were also asked some general questions about their organisation, the site they worked at and the plant area being considered. These questions were designed to allow identification of any trends.

QUESTIONNAIRE SURVEY

It was felt that a ‘before and after’ perspective of implementation of remote operation would create a greater appreciation of the human factors issues. Consequently three variations of the questionnaire were developed. One for organisations where there had been a change, one where a change was planned and one where there had been no change. Similar questions were asked in each of the questionnaires. The three streams provided an opportunity to see whether a change had left the participants more sensitive to the remote operation issues identified in the literature survey.

The emphasis of the questionnaires was not to on generating detailed statistical analysis; the sample was not large enough for this form of analysis. The aim was to elicit qualitative, descriptive information to support or contradict the findings of the literature survey.

The topics contained in these questionnaires were based on a combination of the areas identified in the literature survey, HRA’s experience in the process industries and were refined following test administration at two high hazard process sites. Cosmetic modifications to the questionnaires were made after 17 questionnaires had been sent out and 5 had been returned. The six basic sections of the questionnaire are described below:
Section 1: Description of process unit
Respondents were asked to provide descriptive information regarding the process unit identified for further analysis. This included a brief sketch of the process unit layout, a description of the control room structure, the control systems used and the organisation of work. The goal of this section was to provide context for the rest of the answers.

The questions asked in this section were chosen to establish how well the definition of remote operation used in the literature review related to current industry practices and how operations are arranged to manage the key aspects of secondary information and communication in information acquisition.

Section 2: Description of the change
This section involved a detailed description of what the change had meant for the organisation of work in the process unit. Respondents were asked to describe what the changes had meant for control systems, automation, centralisation, manning levels, shift patterns, working arrangements and shift handover and, if possible, to describe why the changes had been undertaken. The aim of this section was to establish typical patterns of change. For example, do organisations change only one aspect of a system at a time, or is it more usual for several aspects to change simultaneously?

The literature review highlighted that the degree of remoteness in process plant operation is determined by a complex interaction of factors. The questions in this section were chosen to confirm that operation is generally becoming more remote and to establish which aspects of operation were subject to the greatest change.

Section 3: Description of process information acquisition
This section required a description of the impact that the change had had upon the way that Control Room Operators received information about the plant. The literature review had identified information as a key tool for successful management of remote operation. This section sought to identify the affect of the change on the way operators receive information about the plant they control. The respondent was required to assess the proportions of information obtained from a variety of sources (e.g. VDUs, local gauges, direct perception) and how the change had influenced these proportions.

The literature review identified that acquisition of process information involves two main elements: the channel of transmission and the display. In general, process information to be transmitted is the same on each plant (i.e. temperature, pressure, flow); hence the questions in this section were chosen to establish the method of display used in remote operation.

Section 4: Description of communication
This section required a similar analysis to the previous section; here the focus was on communication of information between operators. Respondents were required to assess the proportions of different communication techniques used (for example, face-to-face, radio, email, etc.), before and after the change.

The literature review identified that communication involves three main elements: a sender, a receiver and a channel through which communication passes. In general the sender and receiver of information during process operation are the same on each plant (i.e. Control Room and Field Operators). Hence the questions in this section were chosen to identify the channels of communication used, in particular to establish the extent to which face-to-face communication changes as operation becomes more remote.

Section 5: Discussion of benefits and problems
In this section, respondents were asked to discuss the benefits and problems caused by remote operation. Respondents were asked to assess these from both the organisation’s and their own perspective. They were also asked whether these had been anticipated and how they were managed.

The literature review suggested that specific benefits and problems would be associated with process information acquisition and communication. The original questionnaire included questions about specific benefits and problems in each section. The early trials of the questionnaire showed that people found it difficult to associate these with particular aspects of their operation. It was decided, therefore, to cover overall benefits and problems in one section.

**Section 6: Review of changes and potential safety implications**

The literature review had identified various areas of work that might be affected by a change in the level of remote operation. This final section was designed to elicit the participant’s opinion on these issues. They were asked whether they felt remote operation had affected these areas and, if it had, did this matter from a safety perspective.

The first questionnaire to be developed was the ‘change’ questionnaire. The ‘future change’ questionnaire was identical to the ‘change’ questionnaire except that the tenses of the questions were altered. For example, ‘Has the organisation formally identified any benefits arising from these changes?’ became ‘Is the organisation expecting any benefits to arise from these changes?’ The ‘no change’ questionnaire was slightly different in that there was no before and after comparison to be made. However, the same sections were included with the exception of Section 2, the change description. A copy of the main change questionnaire is contained in Annex 2 to this report.
APPENDIX 2 – SURVEY OVERVIEW

In preparing the original proposal it was assumed that a relatively simple telephone survey of 60 companies would be conducted. Of those companies it was assumed that 50 would be relevant to this research. During the pilot phase of this project it became apparent that it would be difficult to get “quality” time on the phone with people who were able to answer some of the important questions regarding remote operation, this led to a review of the method.

The actual method used involved a two level questionnaire. The first one asked some basic questions about the use of remote operation. Its purpose was to establish what was happening in industry and to establish trends in different types of company and their operations. In general people were able to answer these questions easily and this element of the survey took less than 10 minutes for each participant. For those companies that agreed to provide information a significantly longer questionnaire (see Annex 2 to this report) was sent via an agreed medium (post, fax or email). We estimated this would take a person knowledgeable about all the relevant aspects of their plant operation about 45 minutes to complete. It was not anticipated that every questionnaire would be returned completed, but it was felt that the depth of information received would compensate for the reduced response rate.

An additional part of the original proposal was to collect about 5 case studies. It was anticipated that these would be collected from site visits lasting up to 5 days. Once again the pilot phase of the survey identified that the method would need to change because there was general reluctance to allow us on site for such a long time (many people stated they felt they had already spent a lot of time on other HSE studies, particularly the Entec manning levels study). It was also established that most companies had carried out so little analysis of remote operation that an extended visit would be of less valuable than had originally thought. Instead a larger number of case studies (11) were collected from shorter site visits. It was felt that that the modified approach was as effective as that originally proposed.

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Overview of survey participation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of telephone surveys completed</td>
<td>68</td>
</tr>
<tr>
<td>Number of questionnaires sent</td>
<td>71</td>
</tr>
<tr>
<td>Number of completed questionnaires received</td>
<td>39</td>
</tr>
<tr>
<td>Number of case studies developed from site visits</td>
<td>11</td>
</tr>
</tbody>
</table>
## APPENDIX 3 – RESULTS OF PHONE SURVEY

### PAST CHANGES

**Table 5**
Overview of changes taking place on plants within last 7 years

<table>
<thead>
<tr>
<th>Index</th>
<th>Major hazard site?</th>
<th>Size of site</th>
<th>Activity</th>
<th>Batch or continuous?</th>
<th>Previously remote</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Yes</td>
<td>Med</td>
<td>Manufacture</td>
<td>Continuous</td>
<td>Yes</td>
<td>Increased automation</td>
</tr>
<tr>
<td>P2</td>
<td>Yes</td>
<td>Med</td>
<td>Manufacture</td>
<td>Continuous</td>
<td>Yes</td>
<td>Operating teams downsized</td>
</tr>
<tr>
<td>P3</td>
<td>Yes</td>
<td>Sml</td>
<td>Manufacture</td>
<td>Batch</td>
<td>Yes</td>
<td>Control room moved</td>
</tr>
<tr>
<td>P4</td>
<td>Yes</td>
<td>Med</td>
<td>Manufacture</td>
<td>Continuous</td>
<td>Yes</td>
<td>New DCS control system installed</td>
</tr>
<tr>
<td>P5</td>
<td>Yes</td>
<td>Lge</td>
<td>Manufacture</td>
<td>Continuous</td>
<td>Yes</td>
<td>Central control room replaced by two more local control rooms</td>
</tr>
<tr>
<td>P6</td>
<td>Yes</td>
<td>Med</td>
<td>Manufacture</td>
<td>Continuous</td>
<td>Yes</td>
<td>New control system installed. Civil upgrades</td>
</tr>
<tr>
<td>P7</td>
<td>Yes</td>
<td>Lge</td>
<td>Manufacture</td>
<td>Continuous</td>
<td>Yes</td>
<td>User interface improved following incident on site</td>
</tr>
<tr>
<td>P8</td>
<td>Yes</td>
<td>Lge</td>
<td>Manufacture</td>
<td>Continuous</td>
<td>Yes</td>
<td>6 controls rooms moved to one central</td>
</tr>
<tr>
<td>P9</td>
<td>No</td>
<td>Med</td>
<td>Manufacture</td>
<td>Batch</td>
<td>Yes</td>
<td>Increased automation</td>
</tr>
<tr>
<td>P10</td>
<td>Yes</td>
<td>Lge</td>
<td>Non-manufacture</td>
<td>n/a</td>
<td>Yes</td>
<td>New layout and instrumentation</td>
</tr>
<tr>
<td>P11</td>
<td>No</td>
<td>Med</td>
<td>Manufacture</td>
<td>Batch</td>
<td>No</td>
<td>Change from manual to computerised operation</td>
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<tr>
<td>P12</td>
<td>Yes</td>
<td>Med</td>
<td>Manufacture</td>
<td>Continuous</td>
<td>Yes</td>
<td>Move of control room location and introduction of DCS</td>
</tr>
<tr>
<td>P13</td>
<td>Yes</td>
<td>Lge</td>
<td>Manufacture</td>
<td>Continuous</td>
<td>No</td>
<td>Moved control room, installed DCS control system and changed shift to include dedicated Control room operators</td>
</tr>
<tr>
<td>P14</td>
<td>Yes</td>
<td>Sml</td>
<td>Non-manufacture</td>
<td>Continuous</td>
<td>Yes</td>
<td>Moved to single manning</td>
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<tr>
<td>P15</td>
<td>Yes</td>
<td>Sml</td>
<td>Non-manufacture</td>
<td>Both</td>
<td>Yes</td>
<td>De-manning and change to control system interface</td>
</tr>
<tr>
<td>P16</td>
<td>No</td>
<td>Med</td>
<td>Manufacture</td>
<td>Batch</td>
<td>Yes</td>
<td>Moved CR from 3rd to 5th floor</td>
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**FUTURE CHANGES**

**Table 6**

**Overview of plants planning to increase amount of remote operation in next 3 years**

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<th>Major hazard site?</th>
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<th>Activity</th>
<th>Batch or continuous?</th>
<th>Currently remote</th>
<th>Description</th>
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NO CHANGE

Table 7
Overview of plants that have and do not plan to make changes to level of remote operation

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## APPENDIX 3 – RESULTS OF QUESTIONNAIRE SURVEY

Changes that have occurred / are planned

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<th>Control system</th>
<th>Level of automation</th>
<th>More centralised?</th>
<th>Manning levels</th>
<th>Shift patterns</th>
<th>Working arrangements</th>
<th>Shift handover</th>
<th>Receiving information</th>
<th>Comms</th>
<th>Benefits</th>
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APPENDIX 4 – CASE STUDIES

CASE STUDY 1

Process
Batch manufacture of very high hazard material

Degree of remoteness
Some tasks performed from behind blast proof wall via simple, manual controls. In some cases, these tasks require local monitoring by a second person located on the plant.

Status of change
No changes have been made to the plant or the way it is controlled for over 20 years, and none planned. However, organisational changes have also affected some non-process activities.

Discussion
The nature of the product being manufactured meant that the plant has to be unmanned for certain activities. This was achieved by building a blast proof wall through which links to some basic instruments and simple control devices were installed. A set or mirrors were installed to allow the operator to visually monitor the plant. These controls thus minimised the time people had to be on the plant and thus minimised the risk of injury in an incident.

Some tasks involve two operators working together, one operating the controls and the other monitoring locally on the plant. As only a wall separates them they are able to shout instructions to each other, and hence do not need radios of telephones. Due to the hazardous nature of the process, they have recognised that accurate communication is essential. They have developed a set of standard phrases that are used to avoid ambiguity. Ideally, more of the process could be operated remotely and video cameras have been installed to allow better monitoring. The operators have found that these are not sufficient for the more delicate operations and so a person on the plant is still found to be necessary.

One area where this plant has become more remote is with regard to the rest of the company. In the past, the site where the plant is located was home to manufacturing and other divisions of the company. Over time most have these have been closed or moved. The plant is now finding that it feels out of touch from what is happening in others areas of the company. Monthly dialogue meetings have continued but without a cross section of the company being located locally, the value of these has diminished. The plant has also found that the administrative systems are no longer suitable for such a small operation.

Summary
The plant does not have the economies of scale that would justify the cost of installing new control technology. It highlights, however, that remote operation is not simply the use DCS from a central control room. In this case, the biggest concern is the remoteness from the rest of the company. They find that systems of work are imposed that are not appropriate for their activities and that there is not the communication mechanism that would allow the issues to be addressed.
CASE STUDY 2

Process
Batch manufacture of fibres. Continuous packing process.

Degree of remoteness
Plant is monitored from a control room separate, but near to the plant. Majority of operations performed manually on the plant.

Status of change
A gradual changeover from an analogue panel to a DCS control system is currently taking place. At the time of the case study, the plant has carried out about 10% of the project. On completion of the project, certain parts of the process will be automated.

Narrative
This plant had an existing control room with an analogue panel. The panel and associated controllers had become obsolete. Also, a change of company owner had added significant production pressures, in the past the plant would have been shut down for about 50% of the time because lack of orders, at the time of the survey demand was starting to exceed capacity.

The strategy the company had adopted was to maintain existing functionality of the control system. Hence, the new system would have the same control loops, trips and alarms. The new DCS did however allow for increased automation. The main use of this was to automate the batch part of the process. The company believed this would remove some of the inconsistencies of product quality currently occurring as it was assumed this was caused by lack of accuracy under manual operation.

The new DCS system also allowed for better data storage and retrieval. This was to be used to analyse the process more carefully. The trend facility was expected to be especially useful.

The company’s decision to phase in the change gradually had been well received by the operators as it was giving them time to get used to the new system. At the time of the survey, relatively few of the control had been transferred to the new system and so there was some concern that confusion may occur as more was transferred. An additional problem was that the new DCS was showing a large number of alarms as data was missing from the parts of the plant still using the old control system.

Summary
The decision to change the control system on this plant was almost taken by default because the existing system had become obsolete and was not sufficient for the needs of the business. The affect on operation of the new system did not seem to have been fully considered. In particular, the fact that some of the process was being automated will inevitably change the way the operators work on the plant but this had not really been considered. By making change gradually, this ensured that at least the early stages of the project were well received by all.
CASE STUDY 3

Process
Oil Products Manufacture – Continuous Process

Degree of remoteness
Control of the plant was moved for safety reasons from a building within the plant area to an existing Control Room about 300 metres away. Two other processes were already controlled from that control room. Although operated remotely the Field Operators were still based in the control room.

Status of change
The move had occurred approximately 6 years prior to the visit.

Narrative
The move of control room had been accompanied by an upgrade to the DCS control system and a reduction in the number of operators on each shift. There had been some improvements in production and costs but none of these were attributed to the control of the plant becoming more remote.

At the time of moving the control room there had been problems with morale because of announced job cuts and the perception that even more may occur in the future. There was also some concern about using the new DCS system but this was managed by installing some of the new VDU screens in the existing control room before the move actually took place.

Moving to remote operation was perceived to have increased the safety of the operators as they now spent more of their time further from the plant. This was balanced to some problems with delays to responding to problems on the plant, although no specific examples were given. The Control Room operators had found, however, that their level of responsibility had increased, although this had not resulted in any change to terms and conditions. This meant that sometimes the field operators had a poorer understanding of the Control Room Operators’ tasks than under the previous working conditions. Whilst the control system was better than previous it was sometimes more difficult to manage under abnormal conditions due to information overload.

Sharing a control room with other processes had been a problem for operators in the initial period after the changeover; the combined control rooms produced a more distracting environment for the operators. This has become less of a problem over time as operators have become more used to the level of distractions.
CASE STUDY 4

Process
Chemical Manufacture - Batch process

Degree of remoteness
Initial operation involved 3 Field Operators working locally. Installing a new control system into a Control Room resulted in plant being operated by one Field and one Control Room operator

Status of change
The move of control was completed in 1995.

Narrative
The plant had decided to move to Remote Operation and build a control room because this seemed to be the trend across the industry. In hindsight the benefits of such an investment were not clear and sister plants have not carried out such changes (see Case study 6 below), especially as the cost of the project went 40% over budget. However, there had been some improvements in consistency of batch quality and it was felt there was less reliance on individuals’ “operating style.”

Several problems had occurred because there was only one Operator working on the plant and many of the process actions were carried out from the control room. In one particular example, a whole batch of product had been lost when a valve had been left open. Recovery would have been more likely if the task had been carried out manually, as operators would have seen the problem developing.

The new control system had increased the amount of the production that was carried out automatically. It was also felt that there was a tendency for the Operators to over rely those systems. This had been exacerbated by the design of the system that had been based on “normal” production. The reality was that the plant was often required to carry out unusual operations.

Communication had increased because of the change, control room operators and field operators now had to communicate to enable them to progress with their work. In the past operators would get on with their activities without telling anybody. This increase had brought an old problem, radio reliability, to the fore. An additional channel of communication had been installed in the form of PLC text device. Control Room Operators could send written task prompts to the Field Operators. Once received, the Field Operators could accept the task and an acknowledgement of the receipt would be sent back to the control room. This assisted both groups with work pacing and kept the control room up-to-date with the activities.

In the immediate period following the change, field operators resented being told what to do by their colleagues in the control room. However, because most operators rotate through roles this problem eased with time.

Summary
Remote Operation of this plant followed the “normal” approach of building a control room and thus generating two operator roles. In this case, there had been over optimism regarding the benefits of the change and several problems have occurred because of it.
CASE STUDY 5

Process
Chemical Manufacture - Batch process

Degree of remoteness
Operation of the plant was automated. On the sister plant this had been achieved by building a control room (see Case Study 5). On this plant a similar control system was installed but was operated locally.

Status of change
The automation of the plant was carried out in 1997.

Narrative
In this case, the installation of computer control system did not result in the Operators becoming more remote geographically. Some aspects of the operation were automated, however, which allowed a reduction in manpower on each shift.

In this case, the management of change was not such an issue. The technology was seen as support of an existing system of work, rather than a new system. It was suggested that the learning from the previous project (Case Study 5) had shown that the benefits of more remote operation could not justify the cost.

Summary
This case study highlights that new technology can be used without making operation more remote. In this case, a tried and tested method of work did not have to change and the expectations of the change were considered more realistic.
CASE STUDY 6

Process
Chemicals manufacture, continuous process.

Degree of remoteness
Control room is located on the edge of the plant, about 200 metres from the furthest point of
the process it controls.

Status of change
Around twelve months prior to the visit the control room had been moved from the middle of
the plant, to satisfy occupied building guidelines. At the same time, a new computer control
system was installed to allow additional automatic safety protection devices to be installed.
The operating teams were also reorganised to ensure the Control Room was occupied at all
times.

Discussion
The designation of the new control room as a clean, overall free area introduced a physical
barrier between the field and the control room. Management felt that this barrier had actually
improved communication and work planning between operators, as they were now obliged to
work as a team. However, it had taken some time for the Field Operators to get used to using
the radios and remembering to carry them on the plant.

Management felt that the plant now had the potential to improve productivity because they
had more information about how it actually operates. This potential had not yet been reached,
however, because the operators had not adapted their operating style and still preferred ‘fire
fighting’. They pointed out that on a “green field site” it would be possible to select teams of
Operators with aptitude for both and control room working. In this case, the team members
were all more inclined to the field operator job.

The Control Room Operators were slightly less positive about the change although
acknowledged that productivity and efficiency had improved. They found that job variety had
reduced.

The Operators main concerns were about the new interface. Not all of the functionality of the
old system had been transferred. The new system also had an irritating delay of a few
seconds in responding to instructions. The way process information was displayed had also
changed and it was perceived as easier to miss some. They cited an example where no one
had noticed a drum had filled up, and so was not available for use when required.

The operators did not appear to trust some of the automatic control systems that had been
introduced. In some cases, this was because they could no longer “pop out” to check things
were working as intended, although they could request a Field Operator to do this. They also
had some concern about the settings on the automatic control. In one case, an operation under
automatic control was programmed to take about a quarter the time that the same operation
had taken when performed manually. To satisfy their concern that this may cause them a
problem they were overriding the control system to manually increase the time of the
operation. Obviously, such actions would negate some of the potential benefits of having an
automatic control system.

Summary
There were some concerns from both Management and the Operators about some aspects of
the move to remote operation. In particular, there were different perceptions of what the
automated system was able to achieve. The organisational and communication aspects of the
change had not been identified as an issue. From our visit, however, it was clear that the
teams had not yet adapted to their new circumstances. They all knew each other well prior to
the changeover and were all well versed in how the plant was organised. Under the new
system, there was very little opportunity for Operators to work together and this may cause
problems in the long term if this aspect is not managed effectively.
CASE STUDY 7

Process
Chemicals Manufacture – Continuous Process

Degree of remoteness
Control of the process was moved from two local control rooms into an existing control room about half a mile from the plant. This move was carried out to conform with occupied buildings guidelines. An analogue panel was replaced by a DCS control system and this allowed the operating team to reduce by 25%.

Status of change
The move of control room occurred eleven months prior to the interview. The de-manning occurred three months after the move of location.

Narrative
The new control room was already occupied by a plant that had moved 2 years previously and was also using the same model of DCS. The impression given was that this experience had made the transition easier.

In this case, despite the distance from the plant, the Field Operators base had also moved to the new Control Room. This gave an opportunity for a large amount of “offline” face-to-face communication. However, the use of radios had increased significantly. In addition, because the field operators now spend more time on their own they are now required to complete written logs of activity.

Management felt that the change had given the operators a greater awareness of the process they were controlling. In particular, they had a better understanding of trends and upsets and that this in turn had led to a higher quality of finished product. They also felt that the comparative isolation of the new control area had reduced distractions from individuals, like contractors, passing through.

The single biggest issue identified was related to the geography of the new layout creating a delay in getting to distant areas of the site. In particular, it now takes longer to get to and shut down failing equipment and there is some concern that this may result in more serious equipment failures, possibly leading to spillage of process material. The use of cameras to monitor critical equipment, an increase automatic protection had been considered but not yet installed.

Although this project involved installation of a modern DCS control system many of the plant instruments and sensors had not been replaced. There was some concern that the high-tech display of information may lead people to believe that the information was now more reliable.

The Operators reported that reliability of communication using radios was a major concern. The plant had a number of areas of poor reception and the use of hearing protection was becoming more prevalent. In the past most of their communication was face-to-face, after the change they estimated 80% was using radios, these were real issues.

Having moved into an existing and occupied control room the Operators had found that they were being distracted by the other operating teams. They have got used to this and found that on balance working in a central control room has less distractions because it is easier to keep contractors and visitors out of the room. The original plan had been to make to the control room even more difficult by making it a ‘carpet slippers’ environment. This plan was scrapped for practical reasons, particularly regarding access for Field Operators.
The Control Room Operators felt that the new arrangements meant they had gained more responsibility. They had become more involved in meetings with senior members of staff. However, since rotation took place there was no status problem between operators.
CASE STUDY 8

Process
Chemicals Manufacture - Continuous Process

Degree of remoteness
The control room had been moved from a location ten metres away from the plant to one that was around 60 metres away from the plant. The change was to comply with the occupied buildings guidelines.

Status of change
The change had occurred approximately two years before the interview.

Narrative
At the same time as the move, the opportunity was taken to update the control system. A total DCS system was installed, replacing the previous part DCS, part pneumatic control system. This change meant that the style of information displayed to the operators had changed markedly. Since the change, 95% of plant status information came from VDU displays in the control room. Previously most had come from analogue displays.

Management felt that communication had been largely unaffected by the change, with 75% of communication conducted via radio before and after the change. The main benefit of the move had been an improvement in the working environment in the control room, although people found lack of natural light to be unsatisfactory. Also the new control system allowed improved trending of process data benefits, which had been of substantial benefit.

There had been some problems associated with the changes that had taken place. Whilst the information requirements of the operators had been considered in the design of the new DCS, there were some teething problems. In hindsight it was felt that the transition could have been much better if the project team had spent longer with the operating team after the transition was complete rather than moving straight onto their next project on the plant.

The operators were relatively satisfied with the way the transition had been managed. They felt that the biggest issue was the difficulty in just popping out of the control room to attend to a task. This was no longer and hence response time had increased. They felt that the working environment was far superior in the new setting.
CASE STUDY 9

Process
Oil Refinery

Degree of remoteness
Control of plants on the site had moved from about five local control rooms into one central control room. The old, existing control rooms had become local bases for the Field Operators. The main reason for the change was a desire to move control to a safer, central location.

Status of change
The change was carried approximately 7 years prior to this interview.

Narrative
During the installation process, a new DCS system was fitted to the control room. In addition, a new process unit was introduced. The increased remoteness was complemented by a general increase in the level of plant automation. In addition, one layer of supervision was removed from the work system.

The main benefits to arise from the change were the introduction of a high-level automatic trip system designed to enable the plant to failsafe. The strong communication culture that existed prior to the change meant that communication was not affected by the increased distance between operators. Radio use was widespread prior to the change.

Despite some change anxiety, it was felt that morale on the plant was boosted by the investment in the new facilities. The new DCS system also provided operators with easier access to a greater range of plant information. Distractions for the Control Room Operators had been reduced, particularly as they had to spend less time dealing with contractors.

In general, it was felt that the implementation of Remote Operation had been dealt with successfully. A major exercise had been undertaken to involve operators from the early stages of the projects inception. They were involved in the graphics building and ergonomics design of the DCS systems and control rooms.

It had been recognized that the greater distance between the operators and the plant made it more difficult to respond quickly to work in the field but additional automation had been installed. They had also introduced cameras to facilitate viewing of the further reaches of the plant, an innovation that had been well received by the operators.

There had been some associated problems that had arisen from the introduction of the central control room. The new central control room had incorporated a permit issuing area. Previously permits had been issued at local control rooms. This meant considerable vehicle traffic around the new control room; this had not been anticipated in the design, leading to heavy vehicle movement in a small area. Visitor numbers in the control room itself had been anticipated, a mimic control room had been installed, where visitors could watch the process without disturbing operators. Having one central control room puts all the control eggs in one basket, here a reserve control system had been built to ensure that if the central control room was made unusable, a flick of a switch could move control to a fall-back location.

Summary
In this case, Remote Operation had been adopted with relatively little problem. It is clear that the project team had recognised potential problems and included additional features to the new system to deal with them. It is interesting to note that in this case a significant change, which is often perceived with dread by many, appeared to viewed positively.
CASE STUDY 10

Process
Chemicals Manufacture – Continuous process

Degree of remoteness
A central control room was planned to cover operation of the whole process. At present, although an integrated process the different units were operated from local control rooms. Those control rooms were to be retained to act as field stations. A new control system was being installed to provide a single type of system for the whole process.

Status of change
The change was in last stages of preparation when the interview was carried out. Several of the plants had started a gradual installation of the new control system. Construction of the central control room had not yet started.

Narrative
The process has been in place for many years on the site. It produces large quantities of a highly hazardous material. Most of the product is used at other plants on the site, by-products are sold to external customers. The plant consists of several units but the process is essentially continuous with little buffer capacity between. The plant had recognised that operating these units separately was causing inefficiency as local decisions were made that sometimes had an adverse affect on productivity.

Availability of modern DCS controllers gave the site the opportunity to centralise control. The overall aim of this was to improve communication between the teams operating the individual units. A decision had been taken that Field Operators would remain relatively local to the units they control, this was because of the distance from the control room to some parts of the plant and to minimise distractions in the control room.

The company had used several techniques during the planning of this project. This included some task analysis and use of the Entec staffing arrangements method, which had been applied to the main COMAH scenarios. Due to the scale of the project, they had recognised it a significant organisational change, and were managing at such. They had also realised impact on operations that would occur, and so the commissioning of the new control system, which had already been started, was being conducted by members of the operating teams. The operating teams were also being actively encouraged to get involved in every stage of the planning.

One particularly interesting activity performed during the planning was to “mock up” several different layouts for the new control room using cardboard boxes on tables to represent the DCS panels. By involving operators in this exercise, they had found this invaluable to determining the optimum layout to facilitate communication between units whilst minimising disturbances.

The new DCS system being installed was seen as a major opportunity to improve the process. Even with only a small proportion installed the data collection and trending had helped diagnose several long term problems. The technical staff had found it particularly useful to be able to analyse plant operations from their offices. The operators reported that although more analysis was being made without their involvement that communication between them and the technical staff had actually improved because their discussions had become more meaningful.

There were some concerns about whether all the existing operators would be able to use the new DCS, especially once it had been moved to the central control room. This was because the existing workforce had not been selected with this mode of operation in mind. The
operators themselves were also concerned that alarm overload may occur and had paid close attention to what was actually being installed.

**Summary**

A major undertaking was being planned. The company had used some techniques to give them an insight into the issues of a central control room but had found little experience from others to help them. In this case great improvements were expected from locating Control Room Operators from different units in the same building. The negative affects of separating the Field Operators were not so clear.
CASE STUDY 11

Process
Large site consisting of several plants manufacturing bulk chemicals

Degree of remoteness
A new central control room was being created that would eventually house all of the processes on the site. This control room would be supplemented by two auxiliary buildings where Field Operators would be stationed. It was anticipated that the level of face-to-face contact between field operators and control room operators would be minimal.

Status of change
At the time of the visit, the building housing the Central Control Room was complete. The first unit was due to be moved in about six, with the remaining on site moving over the next two years.

Narrative
The main driver for the move to a central location was to comply with occupied buildings guidelines. It was also viewed as an opportunity to develop the site as a showcase for new technology with the hope of attracting more processes.

A single supplier of advanced DCS had been established to ensure all the plants were operating on the same system. In addition, there will be an increase in automation to provide a ‘safe park’ facility for the whole site and improvements in the reliability and quality of the output. Manning levels will also reduce by 15% over the next few years to help justify the change on cost grounds.

One of the most interesting aspects of the change is that it is anticipated that control room operators and field operators will have very little face-to-face contact during their working day due to the distance between the control room and the processes. This has been recognised as a potential difficulty and has resulted in several management strategies. The field operators will be based in the old control rooms, which will act as satellite control rooms, subordinate to the new central control room. They will communicate with the central control room using videoconferencing technology in an attempt to replicate face-to-face contact. In addition, field operators will be encouraged to return to the vicinity of the central control room to eat, in the hope that this will give the two groups the opportunity to interact socially.

Because the new roles of control room operator and field operator will be fixed, strategies have been introduced to pre-empt any feeling of status differential between the groups. Field operators will specialise in safety issues and permit control, whilst control room operators will be dedicated to that role.

The project had been justified by significant projected operating costs. Part of the improvement was expected from housing Control Room Operators together so that they would be able to optimise the use of resources from across the whole site.

Some problems had been predicted. Because of the scale of the project an organisational change team had been put together to ensure the softer issues received adequate attention. Shift handovers and local plant monitoring were seen as potential problems as the operating teams for a particular plant were to become more dispersed.

Summary
This was the most ambitious project reviewed in this survey and as it was still in development it is impossible to know exactly how successful it is. In this case, cutting-edge technology was being proposed as a solution to most of the problems anticipated due to the level of Remote Operation being implemented.
Human Factors Aspects of Remote Operation in Process Plants

Annex 1: Literature Review

October 2001
1 INTRODUCTION

1.1 SCOPE OF THE LITERATURE REVIEW

This literature review has been carried out as part of a research project to establish the state of the art of remote operation in the process industry. This review provides a working definition of remote operation and identifies human factors issues that arise when process plants are operated remotely. To achieve these goals, research on remote operation in process settings, research on remote operation in general and other research that may be applicable to remote operation is considered. Most of the information provided here is from the latter category.

The issues identified will be used as the basis for a survey of current practices in industry. It is not anticipated that a review of the literature will provide exhaustive coverage of the critical issues. Therefore, the interview questions will be informed by the literature survey, HRA’s experience in process industries and feedback from the organisations surveyed. The results of the survey are covered in a separate report.

1.2 WHAT IS REMOTE OPERATION?

To understand the human factors implications of remote operation it is necessary to carefully define ‘remote operation’. This helps to limit the scope of the study and to disentangle closely tied concepts such as increased automation, de-manning, multi-skilling and centralisation.

The very nature of process operation means that operations being performed cannot usually be monitored directly. For example, a chemical reaction is rarely directly observed, instead its progress is inferred through monitoring pressures and temperatures. Combine this with the large scale of most process operations and it is clear that all process plants are operated remotely to some degree. It is also clear that remoteness is not solely a function of distance. For example, a soundproof, windowless control room is more remote than a control room that allows its occupants to see and hear the processes they are controlling.

We have chosen to develop a working definition of remote operation in terms of the information sources used by process operators. Vicente et al. (1998) suggested that control room operators gain information from control room panels and alarms, communication with other operators in the control room, communication with operators in the field, written reports of field readings and direct perception of components in the field. Therefore, we have classified the information sources as follows:

- **Direct perception**
  This information is collected using the human senses of sight (can the operator see the plant they control?), sound, smell and feeling (particularly temperature and vibration).

- **Secondary information**
  All process plants use some degree of secondary information, as it is not possible for operators to be adjacent to all the processes they are controlling. Secondary information is state information that is relayed to operators through control room interfaces, using alarms, etc.

- **Communication**
  In addition to secondary information, operators can raise their understanding of the plant through communication with other individuals.
In terms of our working definition, any individual using secondary information or communication to update their understanding of the plant is working remotely. Because communication can be delayed this means that remote control can occur over time as well as space. For example, information left for teams during a shift handover, even if all other aspects of the system were directly observable, this process would be, to some degree, controlled remotely.

1.3 THE DEVELOPMENT OF REMOTE OPERATION IN PROCESS PLANTS

The introduction of new technology has significantly increased the scope for remote operation. Early process plants relied on local gauges and manually operated local valves. The introduction of pneumatic systems allowed indicators and valve controllers to be moved to more convenient, and often central, locations. However, with pneumatics the distance from which the control could be achieved was limited due to pressure drops within the system.

The introduction of computer control has removed any constraints on the distance from which control can be achieved. It is now possible for multi-national operations to be controlled from a single control room using phone lines and the Internet. Although such extremes have not yet been achieved, some relatively simple process operations such as water treatment plants, sugar processing and gas production offshore platforms can be operated unmanned for a large proportion of the time.

1.4 INCENTIVES FOR ADOPTING REMOTE OPERATION IN PROCESS PLANTS

That something is technically possible does not mean it is necessarily desirable. Technology provides significant opportunities for optimised control and reduced costs, particularly through reduced manpower. However, it is not clear whether the trend towards remote control is being carried out with an appropriate consideration for the impact it has on the safety of operation.

In reality, remote operation occurs because of decisions made to satisfy one or more stakeholders. These stakeholders include shareholders, regulators, employees and management. The changes that are undertaken include centralisation, automation, multi-skilling and de-manning. In the majority of cases, remote operation occurs because of one of these changes, rather than as a conscious decision to make operations remote. The reasons for stakeholders requesting these changes include the following:

- Safety - protecting personnel against fires, explosions and toxic releases by positioning control rooms at a distance from the plant, or making them blast and gas proof. In this case, the need to ensure personnel safety may have a negative affect on system safety if increased remoteness has an impact on the safety of plant operations
- Cost - use of automated systems to reduce the number of people required to operate the plant. In this case, operators will be taking responsibility for more plant. This may reduce their depth of knowledge of specific parts of the plant
- Efficiency - centralising control to provide a single focal point from which operators, supervisors and technical personnel can monitor and direct operations. In this case the organisation of operations may be affected with greater boundaries of demarcation between field and control room operators creating remoteness
1.5 REMOTE OPERATION IN CONTEXT

Often when changes are made to a system the success of the technical component is emphasised above all else. However, in any system the technical aspect of the system is only one part of the story. For this reason, our definition of remote operation is based on a representation of a process operation as a complex socio-technical system. That is, it has both technical and human elements. The plant, including its control system, represents the technical component. Every plant also has a group of workers who operate the technical component, within an organisational and management infrastructure. Moreover, every plant operates in an environmental context (Vicente, 1999). The previous section described how this external environment (regulators, competition, etc.) brings pressure for change. A socio-technical system representation is inclusive of the technical aspects of a system but also allows consideration of social, work organisation and communication issues.

People contribute to the reliability of the overall socio-technical system. In particular, workers can play an important role in performing unexpected, essential tasks or intervening in disturbed situations (Rognin & Bannon, 1997). Humans are able to make these interventions because every worker has a level of understanding, or a ‘mental model’ of the system. This understanding is developed through training and experience.

The notion of mental models is used extensively within human factors literature. Wilson & Rajan (1990) suggest that although there is little agreement over the precise qualities of mental models, most research concurs that people form mental models that allow them to describe, explain and predict system behaviour. They list some properties of mental models over which there is agreement:

- Mental models are internal representations of objects, actions, situations, people, etc.
- They are built on experience and observation
- They are simulations run to produce qualitative influences
- They are made up of topography, structure, function or operation of the system
- They may contain spatial, causal contingency relations
- They allow people to predict and explain behaviour
- They underpin people’s understanding and behaviour
- They are instantiated each time they are required, and are parsimonious and therefore incomplete, unstable and often multiple

The concept of mental models is attractive to system designers. Any understanding of how operators conceive, or are likely to conceive, a system should result in better interfaces, training and procedures (Wilson & Rajan, 1990).

To carry out the required tasks and ensure successful plant operation operators must constantly update their mental models. Two basic information types are required. The first is information about the technical status of the plant, for example, flow rates or levels. The second sort of information is about the overall system, for example, an understanding of what other operators are doing at a given time. The workers receive this information from the sources described in the first section of this paper:

- Direct perception
- Secondary information
- Communication

A worker’s precise information requirements depend on the mental model(s) they hold. Of particular importance are their defined roles within the system. For example, a supervisor requires system-wide resource information, whilst a console operator will need exact
information about the aspect of the plant he or she is controlling. The concept of mental models will be used throughout this survey to discuss how the level and quality of information transfer might change with the introduction of remote operation.

### 1.6 SUMMARY

In summary, remote operation is defined in terms of the way workers update their mental models of the plant system. A process that is not being remotely controlled is one that can be observed directly by a single operator who requires no additional communication to control the process. Use of communication or secondary information from sensors or alarms to update these models is remote operation.

The level of remote operation conducted in a process plant is dictated by the design of the plant and subsequent changes. External pressures such as regulation or competition drive these changes.

The subsequent literature review will focus on the key themes of communication and the provision of secondary information. Factors that influence the quality of delivery and receipt of these information sources will be discussed, with particular reference to the impact that remote operation may have upon this.

The following hypothetical examples illustrate how changes to the organisation of a process plant alter the level of remote operation and how the change may be managed.

<table>
<thead>
<tr>
<th>Change &amp; change driver</th>
<th>Information issue</th>
<th>Potential control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bricking up of control room window for safety</td>
<td>No longer possible to directly view the process from the control room</td>
<td>Closed-circuit television camera</td>
</tr>
<tr>
<td>Change to the control system allows a pump to be started from the control room for efficiency</td>
<td>No longer able to sense vibration at start up and detect abnormal noises</td>
<td>Vibration monitor relays information to control room</td>
</tr>
<tr>
<td>Graduate engineers moved to head office as a result of company reorganisation</td>
<td>Reduction in opportunities for operators to discuss technical issues with engineers</td>
<td>Extra process training for operators</td>
</tr>
</tbody>
</table>
2 REMOTE OPERATIONS ISSUES

2.1 COMMUNICATIONS

This section describes how communication occurs, lists the factors that might affect it and describes how these factors might be influenced by remote operation. It has already been suggested that communication has a vital part to play in maintaining operators’ understanding of the state of the system. Majelian et al (1992) found that teams do not necessarily perform better than individuals, because teamwork requires co-ordination. They suggested that for a team to be successful all aspects of the co-ordination between team members must be examined. In particular, the nature of communication links.

Communication can deliver two basic forms of information. Firstly, information about the state of the process plant, this helps update the recipient’s mental model of the plant. Secondly, information about the other human elements of the system (for example, the sender), this information helps to update the recipient’s mental model of the overall status of the system. Factors that influence successful communication will be the same, whether in the context of remote operation or any other environment.

2.1.1 A generic communication model

For the purposes of this review, we suggest that the communication process progresses through three different domains: the sender, the channel and the receiver. The sender generates the communication intention (i.e. realises that something has to be said), encodes the message (i.e. decides how the message should be expressed) and executes the communication (i.e. articulates the message). The first two stages are under the direct control of the sender. Both the sender and the communication channel influence the ‘message execution’ stage. For example, a message might be inaudible due to the sender's poor pronunciation or due to noise interference. Similarly, the communication channel and the receiver influence the ‘receipt of a message’ stage. The final two stages of the communication process, where messages are de-coded and interpreted are completely in the domain of the receiver. This model is a simplification of the communication process but provides a useful framework for identifying possible communication failures influenced by remote operation.

2.1.2 Role of sender

A sender will usually try to provide the minimal amount of information necessary to enable the receiver to understand (Grice, 1975). This means that communication acts are inherently and necessarily ambiguous. Successful communication, therefore, requires the sender and receiver to have a certain amount of shared knowledge.

Encoding a message requires the sender to make some assumptions about the receiver's level of knowledge. These assumptions will establish areas that can be taken for granted, areas of uncertainty and areas where complete ignorance can be assumed. Sometimes a sender can make the wrong assumptions about the receiver's knowledge. Consequently, insufficient information is included in a message to establish a mutual understanding (Orasanu et al, 1997).
### 2.1.3 Role of receiver

The receiver plays an active role in the processing, modification and transformation of a message in order to achieve an interpretation. The inherent ambiguity of messages means that this interpretation is crucial for successful communication.

Drawing inferences in order to facilitate understanding is an automatic process. Everyday speech characteristically includes numerous false starts, slips of the tongue and minor mispronunciations. However, receivers are often not consciously aware of these and perceive the message as it was intended (Marslen-Wilson & Welsh 1978).

To understand a message receivers use their mental models to formulate reasonable hypotheses about the meaning of ambiguous messages. Factors that affect the quality of mental models are discussed in a later section.

### 2.1.4 Channel domain

The transfer of a message between a sender and a receiver occurs through either a verbal or visual communication channel. In this study, communication is broken down into three distinct forms.

- Face-to-face communication
- Real time interactive communication (phone, radio, online e-mail etc)
- Delayed communication (written logs, any form of messages etc)

These distinctions are made primarily based on the type of feedback that is possible. The first two types of channels allow synchronous communication whereas the latter provides asynchronous communication. Messages being sent through the last two channels would normally take place when the sender and receiver are in separate locations. The advantages and disadvantages of these channels of communication are outlined in a later section. One might anticipate that a move to remote operation may increase the use of the second and third forms, whilst reducing the use of the first type.

### 2.1.5 Summary of communication failures

Successful communication occurs when a receiver interprets and comprehends the meaning of the message as intended. A failure of communication occurs when no message is transferred
or when a message is misinterpreted. The ultimate consequence of either type of failure is that the receiver may form an incorrect intention, which if not recovered, will lead to an incorrect action.

Several communication errors can result in these failures. These initial communication problems may occur in the sender, channel or receiver domain and at various stages in the communication process. The following table documents these initial communication errors. The table also lists some factors that may influence the likelihood of such failures. These factors are discussed in more detail in the sections described in the table.
<table>
<thead>
<tr>
<th>Domain</th>
<th>Stage in communication</th>
<th>Initial Communication Error</th>
<th>Communication Failure</th>
<th>Influenced by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication intention</td>
<td>Message is not formulated&lt;br&gt;The sender never intends to send a message, perhaps due to either a lack of understanding of the requirement to do so or because of a competing priority.</td>
<td>Message not acquired</td>
<td>Mental Model of Task&lt;br&gt;Similarity of Worker Mental Models&lt;br&gt;Attention Focus&lt;br&gt;Social Conditions</td>
<td></td>
</tr>
<tr>
<td>Encoding</td>
<td>Message content is incomplete, ambiguous&lt;br&gt;The message is sent but contains insufficient information for the recipient. Perhaps due to an overestimation of the receiver’s understanding or a high workload</td>
<td>Message inadequate</td>
<td>Similarity of Worker Mental Models&lt;br&gt;Attention Focus&lt;br&gt;Social Conditions</td>
<td></td>
</tr>
<tr>
<td>Sender</td>
<td>Message sent to the wrong person&lt;br&gt;May be due to a misunderstanding of who requires the information or a slip of action caused by a heavy workload or distraction. The communication channel used may influence the impact of the failure. For example, a telephone message sent to the wrong person can be remedied instantly, whereas a delayed message, such as email, may not be.</td>
<td>Message not acquired</td>
<td>Communication Channel&lt;br&gt;Mental Model of Task&lt;br&gt;Similarity of Worker Mental Models&lt;br&gt;Attention Focus</td>
<td></td>
</tr>
<tr>
<td>Execution</td>
<td>Message is not delivered on time&lt;br&gt;This may be due to a lack of understanding of the task itself or of the recipient’s requirements. The sender may have been distracted or had a high workload. Again the communication channel used may influence the outcome of a mistimed message.</td>
<td>Message not acquired</td>
<td>Communication Channel&lt;br&gt;Mental Model of Task&lt;br&gt;Similarity of Worker Mental Models&lt;br&gt;Attention Focus&lt;br&gt;Social conditions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Message content is garbled&lt;br&gt;The correct message is sent but is unintelligible</td>
<td>Message inadequate</td>
<td>Attention Focus</td>
<td></td>
</tr>
<tr>
<td>Domain</td>
<td>Stage in communication</td>
<td>Initial Communication Error</td>
<td>Communication Failure</td>
<td>Influenced by</td>
</tr>
<tr>
<td>----------</td>
<td>------------------------</td>
<td>---------------------------------------------------------------------------------------------</td>
<td>-----------------------</td>
<td>-----------------------------------------------</td>
</tr>
</tbody>
</table>
| Channel  | Message retrieval      | Message is distorted during transfer<br>
*Message distorted by equipment used.*                              | Message inadequate    | Communication Channel<br>
Equipment Reliability                                          |
|          | Message retrieval      | Message is lost in transfer<br>
*Message lost by equipment used.*                                   | Message not acquired  | Communication Channel<br>
Equipment Reliability                                          |
| Receiver | Message retrieval      | Message is not retrieved<br>
*The recipient may have failed to appreciate that a message would have arrived at that stage of the task, may have been distracted or busy. The message may have arrived in an unexpected medium.* | Message not acquired  | Communication Channel<br>
Mental Model of Task<br>
Similarity of Worker Mental Models<br>
Attention Focus<br>
Social conditions                                               |
|          | Message decoding       | Message incompletely retrieved<br>
*Similar factors to those above may have occurred but with some indication that a message had arrived.* | Message inadequate    | Communication Channel<br>
Mental Model of Task<br>
Similarity of Worker Mental Models<br>
Attention Focus<br>
Social conditions                                               |
|          | Message decoding       | Message is not de-coded accurately<br>
*This may be caused by a partially retrieved message (see above), through distraction or workload, through a misunderstanding of the sender’s intentions or a lack of understanding of the task itself.* | Message inadequate    | Mental Model of Task<br>
Similarity of Worker Mental Models<br>
Attention Focus                                                 |
2.1.6 Recovery of inadequate messages

An inadequate message or absent message may threaten miscommunication but does not necessarily lead to an overall communication failure. When a message is incomplete or indecipherable, a receiver is aware that the sender is trying to communicate something, and engages in a process of inference to fill in any gaps or make sense of any uncertainties in the message. In many respects, the receiver’s abilities make up for the message inadequacies. Sometimes this activity can lead to a message being restored to a state where a reasonable interpretation can be made.

If the message is too degraded or insufficient to restore, or the receiver is not confident in the repaired interpretation then the receiver will have to decide whether to engage in a recovery process. As long as a receiver realises that understanding is incomplete, then he or she will request clarification (Orasanu et al, 1997).

If no message is transferred then either the sender or receiver may embark on a recovery strategy. This can occur if either the sender or receiver expects a message or reply. For example, if the message were a question for which a reply is needed, a recovery strategy would consist of the sender repeating the question until the required information has been obtained. Similarly, if a receiver needs and expects a message then they will make a request for it to be transmitted.

The likelihood that a sender or receiver would engage in one of these recovery dialogues will depend on a number of factors. These are discussed at a later stage.

2.1.7 Interpretation of an adequate message

If the initial message transfer is adequate or any type of recovery fulfils its purpose then successful communication is still not guaranteed. A message may still be interpreted incorrectly. These types of misinterpretation lead to an ‘illusory understanding’ (Orasanu et al, 1997) where the sender and receiver both believe that they have communicated successfully but in fact the message that is received, interpreted and acted upon is not the message intended.
2.2 FACTORS THAT INFLUENCE THE LIKELIHOOD OF SUCCESSFUL COMMUNICATION

2.2.1 Communication channel

Any change to the way work is organised on a process plant may influence the way that workers communicate. Three types of communication are outlined below along with a discussion of their strengths and weaknesses. It is not possible, therefore, to say that one is better than the other. A change in the degree of remote operation will alter these. A particular danger lies in the assumption that, following a change, workers will continue to communicate the same information in the same fashion. The way, and extent to which, workers communicate with each other are determined as much by social conditions as by the communication channels that are put in place to assist them. Therefore, the issues addressed in this section should be considered in parallel with the later discussions on social conditions, mental model of task and shared mental models.

Indeed, a general feature of this paper as a whole is the close interrelationship between issues. This relationship means that distinctions between issues are largely arbitrary, convenient divisions chosen to aid discussion. In practice, it is important to take a holistic approach to these issues, appreciating that a change to a central control room, for example, will affect the communication channels that are used, which in turn will affect the social conditions under which the workers operate.

Face-to-face communication has several advantages over other modes of communication, including the speed of information exchange possible and the ability to receive instant feedback. In addition, by comparison with telephone encounters, there is freedom to drift in and out of conversation, supplying information when necessary or salient (Drummond & Hopper, 1991).

Moreover, face-to-face communication provides the ability to supplement or replace verbal information with body language. Often, body language will clarify a verbal point that an individual is making, thereby speeding up the transfer of information. Hawkins (1998) notes that there is a vast range of body language with a large degree of universality in its interpretation. In environments where there is a high signal-noise ratio and the possibility of speech masking is high, this form of non-verbal communication can be particularly useful. Stubler & O’Hara (1995) found that gestures and face-to-face discussions aid the collaborative process.

Rognin & Bannon (1997) noted that in situations where several individuals work in the same space, such as control rooms, individually addressed communications can be received by the whole group. This is an efficient way for receivers to infer the intentions and actions of a supervisor without stopping the tasks they are currently engaged in.

Therefore, it is possible that where the introduction of remote operation reduces the amount of face-to-face communication, a rich source of information may be lost. Where face-to-face information is not possible, information that would otherwise be transmitted non-verbally may not be communicated at all. For example, a field operator may communicate a problem to a control room over the radio in a calm manner. The control room operator may miss the message and assume that there is no problem due to the tone of voice.

Real time interactive communications
Radio communication enables users separated by space to communicate with each other. Technical difficulties can cause problems at the retrieval stage (no message is heard, or message content is inadequate). In addition, others can overhear messages, this is similar to the way that others can overhear individually addressed messages in the control room; the
positive aspects of these one-to-many communications were discussed in the previous section. However, it may also create problems where an individual acts upon information that was not meant for them. Moreover, Rognin (1997) suggests that one-to-many communications, as permitted by radio, reduce individual workload but can mean that recipients miss peripheral information.

At a technical level, modular radios place several constraints upon communication. These include the fact that two transmissions cannot be made at the same time, since if two messages are sent at the same time, both are lost (Matthews & Hahn, 1987). Additionally, messages become discrete communication events. A receiver cannot interrupt in the middle of a message to clarify meaning. The sender may also be unsure whether their message has been received.

These constraints increase the need for receivers to read back messages for verification, placing a burden upon communication time available. In an emergency, where information needs to be transmitted rapidly, this could be a major handicap.

Telephones provide a similar function to that of radios. However, telephone communication is more ‘natural’. Two individuals can talk over one another, or interrupt, rather than waiting for a break in the conversation. This is useful in terms of speed but may result in some information being missed. In addition, use of a telephone means one can be sure that a message has been received.

Telephones can be either landlines or mobile. Mobile phones provide the user with the advantage of being able to take the phone to a site being referred to in the communication. However, in a process setting, intrinsically safe mobile phones may be financially unviable.

**Delayed communication**

Delayed communication usually takes the form of visual, written communications. However, delayed messages can be left verbally (e.g. a voice message on a telephone exchange).

Voice messages are similar to those received by modular radio in that they are discrete communication events that cannot be interrupted. Unlike radio communication, however, there may be a considerable delay before information can be clarified. In addition, this delay means that it is harder for the sender to confirm that the message has been received and interpreted correctly. However, voice messages do mean that if the receiver is in any doubt about the information contained within a message they have the facility to go back and check the source at any stage.

If a message is not retrieved by a receiver or the message is inadequate for interpretation, a recovery action may be initiated by the receiver. If the original sender is not present then this recovery action may be unsuccessful. This may be more likely to occur where a delayed communication channel is used. For example, if a written message about the state of a piece of equipment is left by a previous shift and the message is not understood by the new shift, then it cannot be clarified if the sender is no longer available.

**2.2.2 Mental Model of Task**

The concept of mental models was introduced in previous section. Two types of mental model will be addressed in this section and the next. The first represents the basic understanding that the worker has of the task to be done. This understanding comes from two major sources, training and experience of the task. It includes the understanding of how to act in the face of a variety of conditions; what steps need to be taken, what communication is required and when actions need to be carried out.
Training
Without adequate training a worker will not be able to carry out the tasks required, this basic competence, or otherwise, of workers is not within the remit of this work. However, from the perspective of remote operation, good training has the potential to mitigate the impact of issues identified in other sections of this report. For example, training may help a control room operator, who cannot rotate roles with a field operator, gain a more comprehensive understanding of the processes that are being managed in the field giving them a better understanding of when communications are appropriate.

Experience of task
Again, the basic competence of workers is not of concern in this report, unless it is potentially affected by the introduction of remote operation. Milner et al. (1999) suggest that work organisation that results in dedicated control room operators, often leads to an erosion of understanding of the work environment beyond the control room. In this case, the experience of the worker is being directly affected by a system change, with a subsequent implication for performance. This change may affect the ability of the operator to communicate the correct message at the correct time.

Unfamiliarity with a task due to infrequent performance can have various affects on the communication event. If the sender has never performed a task then he or she will be less likely to understand the importance of information. This can lead to incorrect assumptions about the relevance of the message for the receiver, the need to engage in communication or the temporal importance of a message for a receiver’s task. Receivers who are unfamiliar with a task may not expect a communication associated with it or may be less likely to understand its relevance when received.

Responsibility
Responsibility for communication is the same as any other responsibility that an individual has in their job. It is also crucial; failure to understand who has responsibility for a communication act can lead to one of the worst forms of communication error, failure to send a message. Majelian et al (1992) found that communication performance is enhanced where there is a clear allocation of responsibility. Following any change to a process system there needs to be an analysis of how communication has changed and a clear demarcation of responsibility.

Real time interactive communication (something that may become more prevalent after the introduction of remote operation) usually requires a communication protocol. This will involve details of the conversation structure. If no such procedure in place, then a sender may not be expecting a reply and consequently the need for recovery from a message that has not been transferred successfully will not be realised. It should also involve the use of call signs and the International Phonetic Alphabet. The example below illustrates how radio communication can fail without the use of a communication protocol.

Example of communication error (Kletz, 1991)
Kletz (1991) describes an instance where miscommunication had serious consequences. An instruction was given over a radio identifying the recipient by their first name only. Unfortunately, the action was overheard by someone else with the same name, who carried out the action. Remote operation may mean an introduction of more radio communication that carries the potential for this sort of misunderstanding. When this is required, it is important that the communication system is controlled, for example, using defined radio protocol and that the controls are monitored.
2.2.3 Similarity of Worker Mental Models

A second type of mental model is one that links the actions of different workers. Whereas the ‘Mental Model of the Task’ (see previous section) enables fundamental actions to be carried out by the operator, mental models of the task that are shared between operators facilitate successful action through mutual understanding. For example, successful communication will be more likely if the sender can deliver the message at a convenient moment for the receiver. The inherent ambiguity of communication (see Section 2.1) makes this mutual understanding essential. A sender will hold certain expectations about the response to the communication they are initiating. Failure to receive the anticipated response may lead to a recovery of a communication error. Similarly, a receiver holds certain expectations about the content of a message to be received.

The common ground knowledge pre-supposed by the participants in communication can be split into four areas (Orasanu et al, 1997).

- Knowledge and assumptions about the current situation, termed situational knowledge
- Professional knowledge about each participants roles and responsibilities
- Professional knowledge about standard operating procedures, termed procedural knowledge
- Cultural knowledge, e.g. beliefs and norms

A number of factors affect the degree to which communication participants share understanding on the above dimensions, these are discussed below.

**Degree of job similarity**
A group culture, consisting of distinct norms, values and symbols, will usually develop if the same training, experience, tasks, goals and objectives exist. This means that groups develop specific ways of communicating, which satisfy their own needs, and makes the process more efficient. This can include the terminology, phraseology or composition used, and can lead to omission of certain information in a message assumed to be known by other group members. Therefore, where a system change affects the degree of job similarity, or where a new system requires communication between groups that have dissimilar tasks, care needs to be taken to ensure that the various groups are able to communicate efficiently and that the shared vocabulary is sufficient for the task.

In extreme cases, the degree of job similarity may be so small that a sender may not have a clear understanding of the receiver’s information needs. Consequently, a message may lack in detail, or in the worst case may not be communicated at all.

**Time spent working together**
The more two individuals work and interact with one another, the greater the amount of common knowledge will be established. Through working with each other a sense of trust and an understanding of colleague reliability is developed. Artman & Waern (1998) called this understanding ‘cognitive empathy’. They studied communication and co-operation in an emergency response centre; an important aspect of collaboration was the ability of team members to understand the needs of other operators.

Milner et al (1999) agree with this principle where a change is made to a single central control room, from an existing system of distributed control rooms. They noted that although the existing team dynamics may not be ideal, established teams have a well-developed understanding of each other’s strengths and weaknesses.
A disparity between the experience levels of the sender and receiver may also have consequences. A sender who is very experienced at a task may over-assume the competency of others performing the same task. An over assumption of procedural knowledge can cause an experienced worker to omit certain details that seem apparent or self-evident. Power plant operators have been shown to over-assume the degree of common ground between themselves and other team members (Depigny & Gertman, 1986).

**Herald of Free Enterprise (Department of Transport, 1987)**

Ship sank because it left port with its bow doors open

The disaster occurred when the bow doors of a ferry were left open for departure, allowing seawater to enter the vessel, causing it to capsize. The Master of the ferry was required to authorise departure without being able to see whether the bow doors were open or closed. Instead of seeking confirmation, it was assumed that the doors were closed unless a contradictory message was received.

In this case, the Master of the ferry over-assumed the competence of a remotely located individual who held the responsibility for closing the doors.

**Opportunities for sharing information**

Van Daele & De Keyser (1991), using verbal protocol analysis, found that control room operators spend a large proportion of their communication activity positioning themselves within the chronology of action. This helps to update the mental models of the other workers. This information can be supplied verbally or non-verbally. For example, the workload of a member of a control room team can be communicated to all the other members of the control room using body language, such as holding the head, or other behaviours indicative of stress. This suggests that face-to-face communication is beneficial for developing a shared understanding of the system status. It might be suggested that where opportunities for sharing this information are limited, operators may have an underdeveloped understanding of other operators’ activities.

Whilst locating operators in the same room may reduce the likelihood of the above problem, having people in the same room is no guarantee that they will communicate with each other in the manner envisaged by the designer. Milner (1999) reports that central control rooms can reduce the level of communication between operators, due to high workloads. In addition, Milner notes that voice communication (via the telephone) often replaces more efficient face-to-face communication. In a process that is controlled remotely, where teams are distributed across space, informal opportunities for interaction may be reduced. Informal conversations are a good way for workers to assess the relative abilities, experience and reliability of their colleagues. Therefore, remote operation may, exacerbate some of the issues described in this section.

**Similarity of information sources**

Distributed teams may have access to different sources of information. Majelian et al (1992) illustrated the importance of this issue. They examined the performance of teams that were geographically distant but linked by a communication network. They found that teams performed better when the content of information displays was the same for all team members.

**Similarity of goals between individual team members**

Van Daele & De Keyser (1991) noted the importance of shared goals among team members. They suggested that the actions of team with compatible goals reinforce cohesion. Widely distributed teams may find it more difficult to maintain this cohesion. For example, a field operator’s perception of a maintenance task is driven by its complexity, whereas a control
room operator thinks of the same task solely in terms of the effects it will have on production. If the individuals concerned never have the opportunity to meet informally, they may lack awareness of these differing perspectives, reducing cohesion. Again, where these factors are present effort needs to be made to ensure that understanding of the other groups’ working practices is maintained.

2.2.4 Attention Focus

*Multi-tasking/Workload*

Sometimes a worker will have many tasks to perform concurrently. This can cause attention to be diverted away from the required communication act. If the workload is high then the worker might be too busy to formulate a message in a timely manner, or the other task might be incorrectly prioritised.

Similarly, a receiver’s attention may be diverted away from a specific task during the communication act. Concurrent task demands can mean that the receiver’s full attention capacity is used, leaving them unable to receive the incoming message. If the concurrent task does not require quite as much attention capacity, then part of the message may be heard.

In this instance, the communication may make no sense or take a completely different meaning from that intended. The instance where an operator partially hears a message and infers the incorrect meaning from it is a particularly dangerous communication error. It occurs because receivers engage in a process of inference when a message is received. In many cases, a receiver can make assumptions about a communication before it has actually occurred.

It has been established that remote operation may be caused by centralisation or de-manning activities in a process plant. It is important, therefore, to consider the task demands imposed upon operators following the introduction of remote operation.

*Distractions*

If the sender’s attention is distracted then communication acts may be delayed at a critical moment or never carried out. Similarly, distractions may cause a receiver to be diverted away from the relevant communication act. In extreme cases, the receiver may not attend to a message. In face-to-face communication, distractions may be less likely to cause a problem, as the sender will have an opportunity to gauge the receiver’s level of attention through non-verbal feedback.

One distraction in control rooms is unplanned visitors (Pikaar et al, 1990). These visitors may be requesting information or seeking shelter from inclement weather. Control rooms that are distant from a process may generate fewer unplanned visits from field operators, but more from managers and engineers (Milner et al, 1999). This may have negative consequences for attention focus, as operators are distracted from their tasks and expected to provide technical information. In addition, the seniority of these figures may lead operators to feel ‘watched’ and under pressure. On the other hand, impromptu senior visits may increase information flow between these groups, improving social cohesion.

A message can be physically distorted due to environmental noise. Noise refers to any unwanted sound, which interferes with the speech sound. For example, machinery, voices, coughing, etc, this can cause critically important parts of a message to be lost. Consequently the message that it is received may be an unrecognisable form or incomplete. In turn, this can lead to the message trace being incomprehensible or having a completely different meaning than was intended.
2.2.5 Equipment Reliability

Technical problems with communication tools involved in sending and receiving the message may distort the message or even prevent it from reaching the receiver. Clearly, face-to-face communication is not vulnerable to this type of communication deficiency. Interactive and delayed communication on telephones and radios can produce distorted messages. Distortion can include frequency distortion, filtering, amplitude distortion and modification of the time scale (McCormick, 1975). Not all forms of distortion are equally bad. Amplitude, for example, has to be extremely distorted before it has a significant effect on intelligibility.

Partial distortions from electromagnetic interference within a radio or telephone system can cause parts of words or phrases in a message to be inaudible. This can mean that the message takes on a new connotation or becomes unintelligible. Other inadequacies can cause the temporary loss of the transmission of a message. In more severe cases, the whole of the message can be distorted or not transmitted at all. A radio message may be transmitted but the receiver might be in an area without reception. Organisational failures can lead to the unavailability or inadequate maintenance of communication equipment.

2.2.6 Social Conditions

The likelihood of successful communication is also, to some degree, a function of the social environment within which work is carried out. The social environment can be affected in numerous ways by remote operation. For example, the introduction of a central control room increases the degree to which control room operators rely on secondary information. A control panel may be so well designed that, during peak activity, operators are constantly engaged by it, and able to ascertain all the state information they need. However, this also means that also means that opportunities for social interaction are reduced. These opportunities are useful in building the team understanding referred to by Milner et al. (1999).

Milner et al (1999) suggest that a move to a central remote location increases the number of operators that are co-located. Individual preferences for particular light settings or music may conflict. This is also an issue in distributed control centres but the way that work is rotated means operators get their turn to adjust the situation in line with their preferences. Milner et al (1999) feel that these interdependencies are slow to be realised when new facilities are developed. Moreover, operator stress levels, and consequently performance, are affected by the degree of support that an individual receives from workmates or colleagues (Johansson, 1989).

Social issues, like these, are often overlooked as a system changes. An important part of any change management process is to ensure that benefits and drawbacks for the various stakeholders are assessed. Where problems potential problems are identified they need to be addressed.

Whilst these issues may have implications for job satisfaction and morale, they may also affect team cohesion. To mitigate against this it may be useful to ensure that opportunities for informal contact between remotely located team members are provided. Such interaction assists the development of convergent mental models.

**Status compatibility between sender and receiver**

Status appears to have contributed to some failures to request clarification or repetition of messages (Helmreich, 1994). A receiver may be less willing to ask for clarification, if there are large differences in status between the sender and receiver.

One area of particular concern is the tasks that workers carry out. For example, remote control may introduce incentives for management to have specialised control room operators
and field operators. It may not be practical to have field operators moving between work areas and control rooms. This imperative may be compounded if one type of work is felt to be more complex than another. Management may feel, for example, that it is important to have their best operators working in control rooms rather than in the field.

Milner (1999) suggests that such divisions can lead to a perception of inequitable working environments. For example, console operators may feel under more pressure than field operators as their role carries more responsibility. Conversely, field operators may feel marginalised, their career prospects threatened by a lack of opportunity to improve their process knowledge. A lack of opportunity for developing personal knowledge and skill on the job has also been linked to increasing stress levels (Johansson, 1989). Moreover, an individual who enjoyed the variety of rotating between the control room and the field, may resent the sudden imposition of a fixed working environment.

Therefore, changes to the process system may result in status differences between operators developing. These changes can be perceived by workers; for example, a belief that more able operators are being posted in control rooms. Status changes may also be explicitly recognised by an increase in wages. In either situation, there may be implications for communication.

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**Pemex Mexico–LPG Fire and Explosion (542 fatalities)**

In this incident a LPG storage and distribution centre was supplied by a 500km pipeline from a refinery via a pump station about 40km from the site. Local people reported the smell and noise of a gas leak at about 3am but the operator monitoring the pipeline did not notice a drop in pressure for several hours. At 5.40 am a gas cloud ignited, initiating a chain of explosions.

Again, this is an important issue for remotely operated processes, things that are easy to detect in person are difficult to represent in a control room. A control room typically tells an operator what is going in and out of a system and what is happening to it. It is difficult for a control room display to represent a leak or drip that has steadily been getting worse for several days. Moreover, the measures that the control room operator possesses tend not to describe to the operator exactly what is wrong. In this case, for example, the indication was a delayed pressure drop.
2.3 SECONDARY INFORMATION

The second source of information that facilitates remote operation is secondary information. That is, information that is sensed remotely and presented to operators using alarms and display screens. As with communication the information that is presented to operators is felt to be relevant to their tasks. However, unlike communication there is a far greater level of predetermination, in that it is the system designer who decides what information the operator will need. Moreover, whereas communication is used to supply information about both the plant status and the status of workers, secondary information tends to focus on the former.

Many of the factors that were discussed in the previous section, such as attention focus, workload, mental models, equipment reliability and social conditions, have an impact on the acquisition of secondary information as well as communication. For example, workload will have a similar influence over both the likelihood of successful communication and the likelihood of successfully acquiring information from a control panel. To save repetition, only additional information specific to the acquisition of secondary information is included in this section. A related point is that research regarding secondary information and directly relevant to remote operation was fairly scarce. A deliberate decision was made to include only information that was considered germane to this particular topic. Much more information is available about issues such as interface design and alarm systems but this is just as relevant to non-remote operation.

2.3.1 A generic model of secondary information transfer

As with communication, discussed in previous sections, a basic model has been generated to represent the various stages of secondary information transfer. The model has some similarities with the communication model; for example, there is a channel through which the information is communicated and a human receiver to accept the message. The difference between the models is in the first domain, data sensation. In the communication model, the transfer of information was governed to some extent by hardware and system factors, such as location of phone points and procedures relating to information transfer. However, both the sender and receiver had discretion over when information was transferred and, to some extent, the communication channel used.

In this model, the first ‘sensor domain’ is decided during the design of the system and is consequently fixed. The system designer decides that data is useful to the operator and locates a sensor (e.g. heat, level, smoke, etc.) to discern it. The system designer then decides how to present this information to the operator (e.g. alarm, trend graph, etc.) in the channel domain. Again, the designer largely fixes this presentation (although there is a move to allow operators more control over the interfaces they use, see discussion in Section 2.44). The final ‘receiver domain’ is similar to the receiver domain in the communication model. In particular, the likelihood of successful reception is affected by similar factors such as workload and distractions.

2.3.2 A summary of secondary information transfer failures

Successful secondary information transfer involves detection, interpretation and comprehension of the meaning of the information transferred. A failure occurs when recipients have not acquired the information or if the information is inadequate for their needs.

Several errors can result in these failures. The following table documents the initial errors that can occur in each of the stages of information transfer.
<table>
<thead>
<tr>
<th>Domain</th>
<th>Stage in information transfer</th>
<th>Initial information transfer error</th>
<th>Information transfer failure</th>
<th>Influenced by</th>
</tr>
</thead>
</table>
| Sensor     | Data Sensation                | Data not sensed  
*This is due to either a failure in the sensor itself or a design decision not to include a sensor in the location necessary or of the type necessary.* | Information not acquired     | Equipment Reliability  
Sensor design |
| Channel    | Data transfer                 | Data not transferred  
*In this case the data has been sensed but is not transferred to the interface. This is due to the hardware reliability* | Information not acquired     | Equipment Reliability                          |
|            | Information display           | Data not displayed  
*Again this failure will be caused by hardware reliability.*                                      | Information not acquired     | Equipment Reliability                          |
| Receiver   | Information retrieval         | Information is not retrieved  
*This failure may be influenced by a variety of factors such as the recipient’s understanding of the interface and the task they are conducting, workload or distractions or even the level of automation* | Information not acquired     | Interface Design  
Mental Model of Task  
Attention Focus  
Automation |
|            | Information incompletely      | Information incompletely perceived  
*Similar factors to those discussed above may affect the likelihood of incomplete perception*     | Information inadequate       | Interface Design  
Mental Model of Task  
Attention Focus  
Automation |
|            | decoding                      | Information is not interpreted accurately                                                              | Information inadequate       | Interface Design  
Mental Model of Task  
Attention Focus  
Automation |
2.4 LIKELIHOOD OF SUCCESSFUL SECONDARY INFORMATION TRANSFER

2.4.1 Mental Model of Task

This concept of task mental model has already been discussed at length. Further discussion in this section will be limited to the implications for transfer of secondary information.

Experience of task

Milner et al. (1999) suggest that one potential outcome of the change to remote operation may become a change in the operating style of the workers. They postulate that as the control room operator’s experience of the task is now mainly achieved in a location distant from the process they control. They may become more risky in their actions as consequences are less immediate. They describe the mode of operation as ‘playing a computer game’.

2.4.2 Equipment reliability

This review is concerned chiefly with the human factors implications of remote operation; hence, it shall not dwell on the hardware aspects of a process control system. However, it is obvious that where operators rely on instruments for their understanding of a system, as is likely to be the case under remote operations, failure of a sensor may reduce their awareness of potential problems.

Moreover, where operators are aware that a piece of hardware is unreliable they may customarily ignore, or give reduced precedence to, information that comes from it. An example of this was the Kegworth air crash; the pilots formed a (incorrect) hypothesis regarding the nature of the problems they were facing based on a variety of information sources. However, a vibration gauge that contradicted their diagnosis was ignored. That particular gauge had a history of unreliability in previous models of the aircraft.

This has implications for system design. The importance of information needs to be carefully considered by the designer. For critical information sources, operators need to be aware when a source has failed. Reliable, contradictory information should lead operators to question the validity of the conflicting sources and take steps to ascertain which is correct. Where operators are some distance from process, confirming and disconfirming sensor readings may be more difficult and involve communication.

2.4.3 Sensor Design

Sensor Location

A fundamental aspect of any process that is to be controlled remotely is what needs to be sensed and how. The example on the following page illustrates the dangers of a sensor being incorrectly located.

The incident occurred because the operators were incorrect in their assumptions about what was being measured by the sensor. Two issues are important: firstly, where should designers place sensors to ensure that operators have the best understanding of the system they are working with? Secondly, how much experience of the actual plant do remote operators require to operate efficiently?

There is a danger in moving a control room to a more remote location and assuming that control room operators will need no more information. What needs to be assessed in this situation is the informal use that operators make of the information available to them by sticking their head around the door of the control room. A control room can provide all the technical information that an operator needs; however, direct perception is a vital source of confirmatory or contradictory information.
In this incident sludge in a vessel was being heated. The operators identified that the temperature should not exceed 90°C. However, the operators were remote from the process and did not realise that the temperature sensor was above the level of the sludge. The temperature increased to the point where an explosion occurred.

In this case, the operators did not know enough about how their instruments functioned. If they had been monitoring a local temperature gauge, they would have been able to see where it was located on the vessel and more likely to realise that the indication was not accurate enough for their need. In addition, an individual monitoring the temperature locally would have been more likely to note other indications of overheating.

**Sensor modality**
In addition to sensor location, the type of information sensed will also be important to the remote operator. The basic information recorded for an operator to understand the technical status of a process is relatively simple for a system designer to ascertain. The challenge brought by remote operation is that operators are often forced to diagnose emergencies through a process of inference. For example, rather than directly viewing a leak and reacting accordingly, a remote operator will know that pressure has fallen, postulate several hypotheses as to why the pressure has fallen and select ‘leak’ as the correct answer. This conclusion will be arrived at using a combination of confirming and disconfirming information and, in the worst case, likelihood. With critical operations, operators are likely to be taught to be cautious and shut down processes where there is the likelihood that a severe problem has developed. If it is difficult to confirm or deny a situation, this may lead to production losses with multiple, unnecessary shutdowns.

Prior to this incident, a pump stopped which resulted in a high level in a vessel. Both these events caused alarms in the control room but the operators did not respond. When an alarm is included by a designer, it is assumed that operators will respond to it. The fact that operators sometimes don’t respond has implications for the design of alarm systems. Particularly, where the alarm refers to a critical aspect of the system that an operator has no other information regarding.

When the operators did realise the pump had stopped they went out to the plant and started a spare. When they were happy that it had started, they returned to the control room. However, the pump was poorly aligned and started to vibrate. If the operators had been located locally, they may have heard this vibration which was severe enough to cause the line work to fail. Even if they had not prevented the failure, proximity would have made the subsequent leak easier to detect and isolate. In fact, the first indication of a leak was a flammable gas alarm in the control room. When they went to investigate a gas cloud had already formed and a fire was inevitable. Operations that are controlled remotely face this problem. It is unrealistic to sense and reproduce in a control room all of the things that can be noticed about a system from simply walking around it.

However, more dangerous is the situation where an operator cannot confirm or deny a problem, is aware that shutdowns are costing the organisation money and decides that the balance of probability is that it is not likely to be a severe problem. Where a process is controlled locally, it is relatively easy to establish that there is a leak, or an oil drip that has been getting worse for several weeks. The remote operator, however, is unlikely to be
supplied with an ‘oil drip’ sensor by the system designer. The challenge is to provide the right sort of information for operators to make realistic diagnoses. However, this may still need to be supplemented by field operators who walk around the process itself.

2.4.4 Interface design

In terms of information retrieval the problems that operators face have changed considerably over the years. These changes have reflected the shift in the type of interface used by operators in process plants. Broadly speaking this change has been from static hard-wired representations of the system to flexible, computer-based systems where the operator has considerable control over how information is presented. Vicente et al. (1998) characterise this difference using the concept of ‘degrees of freedom’. With hard-wired designs the way the designer chooses to present information is ‘frozen’ into the system. Consequently, there are no degrees of freedom. Conversely, computer based displays have many degrees of freedom, in that operators can choose how they want information to be presented. Therefore, different control room designs can result in different strategies for retrieving information. It might be suggested that more modern control rooms require the operator to have a comprehensive understanding of the interface itself, in addition to the processes being controlled.

Alarm design

Alarms are a particular form of interface. They will be dealt with separately here because of their importance within a process setting. The key issue that must be addressed by alarm design is that when operators are under the most time pressure, during disturbances, they are required to deal with the most alarms (Mattiasson, 1999). Changes to the process plant environment may exacerbate this problem. For example, de-manning and centralisation may lead to operators being responsible for far larger areas of plant. Booth & Pedley (1999) reported that following the introduction of a remote, central control room to control water distribution; alarm management was a particular difficulty during abnormal conditions (e.g. storms).

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**Texaco Milford Haven (HSE, 1997) – Refinery Explosion and Fire**

Several of the contributory factors in this incident were related to remote operation. One problem was that a control valve stuck shut, but was shown as open on the DCS. This illustrates that where operators are reliant on secondary information they are reliant on both:

- The displays being able to show the information they need (this was not the case in the Hickson & Welsh example)
- The sensors working properly (which was the not the case in this example)

If the valve was manually operated, it could not have stuck shut without the operator realising. Secondly, no one realised the knockout vessel level had risen. The level was shown on the DCS but the control room operator was occupied controlling other parts of the plant and missed the high level alarm. DCS allows a lot of information about the plant to displayed from a single, remote location. This does not mean that the operators can actually deal with all that information, particularly when there are problems with the plant. In this case, local operation may have increased the chance of the high level in the knock out drum being noticed because responsibility would have been more clearly defined on geographical grounds.
Finally, everyone, including Supervisors, were busy dealing with the immediate problems with the plant as they saw them. No one took an overview or paid much attention to other parts of the plant. It is easy to assume that having information about all areas of the plant available in one location, the control room, that people will automatically take an overview. It is important that where control is centralised, care is taken to assign responsibility for critical roles.

2.4.5 Attention Focus

Multi Tasking/Workload

In his review of the stress literature Johansson (1989) identified operator workload and in particular repetitive or monotonous work and/or too much work to do in a short space of time as a factor in the stress levels felt by process workers. A particularly stressful combination is a shift from low-level monotonous work to a demanding high-level workload at unpredictable intervals.

A change to remote operation may increase the nature of workload, in addition to the level of work. For example, care needs to be taken when the workers responsible for routine checks are moved to a more remote location. These checks may become more difficult to undertake. Previously, it was easy enough to carry out the checks during a quick walk outside the control room at the start of the shift. Because it was so simple to carry out this task no procedure was necessary. However, since the control room was moved to a remote, central location, the tasks became much more difficult to carry out quickly. It began to require a scheduled activity or a request for assistance to a field operator, on several occasions the checks were inadvertently omitted by shifts. This is an example of how a particular task can retain identical content and yet the change of context results in unforeseen difficulties.

2.4.6 Automation

Roth & O’Hara (1999) studied the introduction of advanced alarms, displays and computerised procedures in a nuclear power plant control room. Their findings illustrate the changes to a system that can be brought about through the introduction of new technology. It also demonstrates that changing one aspect of a system, to more remote operation for example, inevitably affects other aspects, and that the implications of any changes needs to be considered carefully from a system-wide perspective.

They looked specifically at the way that change affected the work relationship of three team members; information gathering reduced and the operators worked more in parallel, reporting a greater confidence in their situation awareness. However, because they were able to work more easily individually, a greater effort was required to maintain awareness of each other’s actions. The shift supervisor, in particular, needed to remember to remind the crew of the status and direction of the path he was taking through the procedures.

The consequences of the introduction of advanced control systems have been well explored within the human factors literature (see, for example, Bainbridge, 1987). Hallbert et al (1997) warn of the importance of keeping the control room operator within the process loop. They suggest that if the operator’s main function is to monitor the plant state, then it is difficult to develop and maintain an understanding of the system. This has the effect of rendering a valuable defence against error largely impotent. They also stress that thee should not be a policy of automating everything that can be automated. This allocation of function tends to leave operators with the most complicated tasks to perform when automation cannot cope. In addition, because the automation has reduced the opportunities that the operator has to operate the system, operator intervention will become more difficult.
Higher levels of automation and advanced control systems have been linked with stress in operators. In his review of the stress literature Johansson (1989) listed several factors over which there is agreement in the literature. One factor that contributes to stress levels is an individual’s perceived control of a situation. This may be affected by a change in the level of automation.

3 CONCLUSIONS

The principle challenge when a process is remotely operated is to ensure that operators have all the information they need to carry out their tasks safely and efficiently. This review has looked at the three main ways that operators can receive information about their plants; through direct perception, communication with others and from secondary sources such as displays and alarms. A remotely operated process makes the first form of receipt difficult and increases the prevalence of the latter two. Little research has addressed these issues directly; perhaps because an increase in remote operation usually occurs in parallel to, or as a consequence of, other changes such as increased automation, de-manning or centralisation of control. Despite this, anecdotal evidence and incident reports cite causes of upsets that would have been unlikely to occur had the process been locally controlled.

To compensate for a lack of direct research, this review has sought to identify factors that might influence the success of these forms of information transfer and to speculate how these factors could be affected by an increase in remote operation. For example, the introduction of a central control room will mean that face-to-face communication between field operators and control room operators will be largely replaced with radio communication. In principle, the two groups are communicating the same information they always have done, in practice the remoteness between the groups may result in a lack of understanding of each others roles and responsibilities affecting the quality of the information communicated.

Of the three sources of information identified as crucial to the success of remote operation (direct perception, communication and secondary information), it appears that very little research has been carried out into the importance of direct perception as a source of information to operators of safety critical systems. Much more research has been conducted into secondary information sources, in particular in areas such as alarm and interface design. However, this is infrequently considered within a remote context. Of the three, the most applicable research was found in the communication area, where subjects such as distributed teams have prompted consideration of issues such as operator mental models and how these vary as opportunities to interact reduce.

This work and the table on the following page summarise some potential areas of concern that should be considered when a remotely operated process is introduced. It is the responsibility of the organisations managing the change to consider these issues and determine the change’s potential impact, its likely significance, and how best to manage it.
Table 3
Summary of factors influencing the success of remote operation

<table>
<thead>
<tr>
<th>Influencing Factor</th>
<th>Communication Channel</th>
<th>Mental Model of Task</th>
<th>Similarity of Mental Models</th>
<th>Attention Focus</th>
<th>Equipment Reliability</th>
<th>Social Conditions</th>
<th>Sensor Design</th>
<th>Interface Design</th>
<th>Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage</td>
<td>Message not formulated</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Message content is incomplete, ambiguous</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Message sent to wrong person</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Message is not delivered on time</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Message content is garbled</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Message is distorted during transfer</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Message is lost in transfer</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Message is not retrieved</td>
<td>X</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
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<td>Message is not retrieved in its entirety</td>
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<tr>
<td></td>
<td>Message is not decoded accurately</td>
<td></td>
<td></td>
<td>X</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Influencing Factor</td>
<td>Communication Channel</td>
<td>Mental Model of Task</td>
<td>Similarity of Mental Models</td>
<td>Attention Focus</td>
<td>Equipment Reliability</td>
<td>Social Conditions</td>
<td>Sensor Design</td>
<td>Interface Design</td>
<td>Automation</td>
</tr>
<tr>
<td>--------------------</td>
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</tr>
<tr>
<td>Data not sensed</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Data not transferred</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Information not displayed</td>
<td></td>
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<td></td>
<td>X</td>
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<td></td>
<td>X</td>
</tr>
<tr>
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<td>X</td>
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<td></td>
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<td></td>
<td>X</td>
</tr>
<tr>
<td>Information is not interpreted accurately</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
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</table>
REFERENCES


Cullen (1990) *The Public Inquiry into the Piper Alpha Disaster*.


HSE (1994) *A report of the investigation by HSE into the fatal fire at Hickson and Welch Ltd. Castleford on 21 September 1992*.


Human Factors Aspects of Remote Operation in Process Plants

Annex 2: Questionnaire Sample

October 2001
Questionnaire: Human Factors Implications of Remote Operation

Introduction
As part of an agreed research contract with HSE’s Hazardous Installations Directorate (HID), HRA have been asked to investigate human factor aspects of remote plant operation in the process industry. This questionnaire forms an important part of the research. The results of this survey will be used in an HSE Contract Research Report which will be freely available on their website. Anonymity for participants will be strictly maintained. The aim of this project is to develop guidance on human factors issues to be considered by sites where operators and control rooms are, or will be moved, remote from the plant.

The two areas that we are particularly interested in are:

- How workers get information about the process (e.g. VDUs, dials, etc.)
- How information is communicated between workers

Organisation of interview
We have already spoken to you about a particular unit on your plant. Please complete this questionnaire with reference to that unit. We would be grateful if you could fax the completed questionnaire to us. We will then telephone you again to clarify anything we do not understand.

Please fax to Jamie Henderson on 01257 463810

If you have any queries you can also phone Jamie on 01257 463121

<table>
<thead>
<tr>
<th>HRA Project Manager</th>
<th>HSE Project Manager</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr Andrew Brazier</td>
<td>Mr John Wilkinson</td>
</tr>
<tr>
<td>Human Reliability Associates</td>
<td>HM Specialist Inspector (Human Factors)</td>
</tr>
<tr>
<td>1 School House</td>
<td>HSE HID Human Factors Team</td>
</tr>
<tr>
<td>Dalton</td>
<td>St Anne’s House</td>
</tr>
<tr>
<td>Lancashire</td>
<td>Stanley Precinct</td>
</tr>
<tr>
<td>WN8 7RP</td>
<td>Bootle</td>
</tr>
<tr>
<td></td>
<td>Merseyside</td>
</tr>
<tr>
<td></td>
<td>L20 3RA</td>
</tr>
<tr>
<td></td>
<td>(0151) 951 4000</td>
</tr>
</tbody>
</table>

www.humanreliability.com
information@humanreliability.com
Unit identified during first questionnaire:
Change identified during first questionnaire:

The current organisation of work in the unit
Please draw a simple plan showing approximate locations of, and indications of distance between, control rooms, process equipment, maintenance workshops, management offices, local control panels, etc.
### 1. Human Factors Implications of Remote Operation

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 How many control rooms are there in the unit?</td>
<td></td>
</tr>
<tr>
<td>1.2 What control systems does the unit use?</td>
<td></td>
</tr>
<tr>
<td>1.3 How is process information displayed to operators? (e.g. VDU screens, hard wired, local gauges)</td>
<td></td>
</tr>
<tr>
<td>1.4 What workers are there on this unit?</td>
<td></td>
</tr>
<tr>
<td>Worker role</td>
<td>Number</td>
</tr>
<tr>
<td>Control room operator</td>
<td></td>
</tr>
<tr>
<td>Field operator</td>
<td></td>
</tr>
<tr>
<td>Supervisor</td>
<td></td>
</tr>
<tr>
<td>Others (please describe)</td>
<td></td>
</tr>
<tr>
<td>1.5 Do the control room operators remain in the control room for the whole shift?</td>
<td>YES</td>
</tr>
<tr>
<td>1.6 If NO, please describe when and why they leave it?</td>
<td></td>
</tr>
<tr>
<td>1.7 How are breaks covered during the shift?</td>
<td></td>
</tr>
<tr>
<td>1.8 Are the workers dedicated to those roles or do they rotate between them?</td>
<td>DEDICATED</td>
</tr>
<tr>
<td>1.9 If they rotate, please describe how they do this:</td>
<td></td>
</tr>
<tr>
<td>1.10 What training do control room operators receive?</td>
<td></td>
</tr>
</tbody>
</table>

### 2. The effects of the change upon the way work is conducted in the unit

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 Has the control system changed?</td>
<td>YES</td>
</tr>
<tr>
<td>2. If YES, please describe in what way it has changed</td>
<td></td>
</tr>
<tr>
<td>What was the reason for the change?</td>
<td></td>
</tr>
<tr>
<td>2.2 Has the level of automation changed?</td>
<td>YES</td>
</tr>
<tr>
<td>2. If YES, please describe in what way it has changed:</td>
<td></td>
</tr>
<tr>
<td>What was the reason for the change?</td>
<td></td>
</tr>
<tr>
<td>2.3</td>
<td>Has control become more centralised?</td>
</tr>
<tr>
<td>-----</td>
<td>-------------------------------------</td>
</tr>
<tr>
<td></td>
<td>If YES, please describe in what way it has changed:</td>
</tr>
<tr>
<td></td>
<td>What was the reason for the change?</td>
</tr>
<tr>
<td>2.4</td>
<td>Has there been a change in the manning levels?</td>
</tr>
<tr>
<td></td>
<td>If YES, please describe in what way it has changed</td>
</tr>
<tr>
<td></td>
<td>What was the reason for the change?</td>
</tr>
<tr>
<td>2.5</td>
<td>Has there been a change in shift patterns?</td>
</tr>
<tr>
<td></td>
<td>If YES, please describe in what way they have changed</td>
</tr>
<tr>
<td></td>
<td>What was the reason for the change?</td>
</tr>
<tr>
<td>2.6</td>
<td>Have working arrangements changed (i.e. self managed teams, multi-skilling)?</td>
</tr>
<tr>
<td></td>
<td>If YES, please describe in what way they have changed</td>
</tr>
<tr>
<td></td>
<td>What was the reason for the change?</td>
</tr>
<tr>
<td>2.7</td>
<td>Has there been a change in shift handover?</td>
</tr>
<tr>
<td></td>
<td>If YES, please describe in what way they have changed</td>
</tr>
<tr>
<td></td>
<td>What was the reason for the change?</td>
</tr>
</tbody>
</table>
### 3 Has the way control room operators receive information from the plant or process changed?

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Have the changes described above affected the way information is received?</td>
<td>YES</td>
</tr>
<tr>
<td>3.2</td>
<td>If YES please describe the change:</td>
<td></td>
</tr>
</tbody>
</table>

#### 3.3 How is information received?

<table>
<thead>
<tr>
<th>Information source</th>
<th>% of information obtained from this source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local instruments (on equipment)</td>
<td>% Before change</td>
</tr>
<tr>
<td>Local control panels (in field)</td>
<td>% Before change</td>
</tr>
<tr>
<td>Analogue panel in control room (pneumatic etc.)</td>
<td>% Before change</td>
</tr>
<tr>
<td>VDU in control room (DCS etc.)</td>
<td>% Before change</td>
</tr>
<tr>
<td>Direct sensation (see, hear, feel)</td>
<td>% Before change</td>
</tr>
<tr>
<td>Other changes (please describe)</td>
<td>% Before change</td>
</tr>
</tbody>
</table>

### 4 Has the way the control room operators communicate with other people changed?

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Have the changes described above affected communication?</td>
<td>YES</td>
</tr>
<tr>
<td>4.2</td>
<td>If YES please describe the effects:</td>
<td></td>
</tr>
</tbody>
</table>

#### 4.3 How does the control room operator communicate with others?

<table>
<thead>
<tr>
<th>Communication method</th>
<th>Approximate % method used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face-to-face</td>
<td>% Before change</td>
</tr>
<tr>
<td>Radio</td>
<td>% Before change</td>
</tr>
<tr>
<td>Fixed telephone</td>
<td>% Before change</td>
</tr>
<tr>
<td>Mobile telephone</td>
<td>% Before change</td>
</tr>
<tr>
<td>Tannoy</td>
<td>% Before change</td>
</tr>
<tr>
<td>Written communication</td>
<td>% Before change</td>
</tr>
<tr>
<td>E-mail</td>
<td>% Before change</td>
</tr>
<tr>
<td>Others (please describe)</td>
<td>% Before change</td>
</tr>
</tbody>
</table>
### 5 Benefits and problems

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Has the organisation formally identified benefits arising from these changes?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>YES</td>
<td>NO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.2</td>
<td>If YES please describe these benefits:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.3</td>
<td>Were these benefits anticipated?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>YES</td>
<td>NO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.4</td>
<td>In your opinion, have any benefits arisen from these changes?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>YES</td>
<td>NO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.5</td>
<td>If YES, please describe these benefits:</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.6</td>
<td>Did you expect these benefits?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>YES</td>
<td>NO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.7</td>
<td>Has the organisation formally identified any problems arising from these changes?</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>YES</td>
<td>NO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.8</td>
<td>If YES please describe these problems:</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>5.9</td>
<td>Were these problems anticipated?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>YES</td>
<td>NO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.10</td>
<td>In your opinion, have any problems arisen from these changes?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>YES</td>
<td>NO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.11</td>
<td>If YES please describe these problems:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.12</td>
<td>Did you expect these problems?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>YES</td>
<td>NO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.13</td>
<td>Was anything done to manage these benefits or problems (either before or after the change was implemented)?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>YES</td>
<td>NO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.14</td>
<td>IF YES, please describe:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.15</td>
<td>Were any formal human factors/techniques used to help manage the change (e.g. task analysis, user involvement)?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>YES</td>
<td>NO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.16</td>
<td>If YES, please describe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
For each question complete section A. Do B where you have identified an increase or decrease. If you are unable to answer section A please leave it blank.

6a **Since the change, operators’ technical knowledge of the process they work upon has…**

<table>
<thead>
<tr>
<th>Reduced significantly</th>
<th>Stayed the same</th>
<th>Increased significantly</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

6b What is the potential impact of this increase/decrease on safety?

<table>
<thead>
<tr>
<th>Major negative impact</th>
<th>No impact</th>
<th>Major positive impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

7a **Since the change, the clarity of responsibility for tasks between team members has…**

<table>
<thead>
<tr>
<th>Reduced significantly</th>
<th>Stayed the same</th>
<th>Increased significantly</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

7b What is the potential impact of this increase/decrease on safety?

<table>
<thead>
<tr>
<th>Major negative impact</th>
<th>No impact</th>
<th>Major positive impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

8a **Since the change, control room operators’ understanding of field operators tasks has…**

<table>
<thead>
<tr>
<th>Reduced significantly</th>
<th>Stayed the same</th>
<th>Increased significantly</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

8b What is the potential impact of this increase/decrease on safety?

<table>
<thead>
<tr>
<th>Major negative impact</th>
<th>No impact</th>
<th>Major positive impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

9a **Since the change, control room operators’ workload under abnormal/emergency conditions has…**

<table>
<thead>
<tr>
<th>Reduced significantly</th>
<th>Stayed the same</th>
<th>Increased significantly</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

9b What is the potential impact of this increase/decrease on safety?

<table>
<thead>
<tr>
<th>Major negative impact</th>
<th>No impact</th>
<th>Major positive impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

10a **Since the change, control room operators’ workload under normal conditions has…**

<table>
<thead>
<tr>
<th>Reduced significantly</th>
<th>Stayed the same</th>
<th>Increased significantly</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

10b What is the potential impact of this increase/decrease on safety?

<table>
<thead>
<tr>
<th>Major negative impact</th>
<th>No impact</th>
<th>Major positive impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

11a **Since the change, operator satisfaction with their social environment has…**

<table>
<thead>
<tr>
<th>Reduced significantly</th>
<th>Stayed the same</th>
<th>Increased significantly</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

11b What is the potential impact of this increase/decrease on safety?

<table>
<thead>
<tr>
<th>Major negative impact</th>
<th>No impact</th>
<th>Major positive impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

12a **Since the change, distractions for control room operators have…**

<table>
<thead>
<tr>
<th>Reduced significantly</th>
<th>Stayed the same</th>
<th>Increased significantly</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

12b What is the potential impact of this increase/decrease on safety?

<table>
<thead>
<tr>
<th>Major negative impact</th>
<th>No impact</th>
<th>Major positive impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Question</td>
<td>Reduced significantly</td>
</tr>
<tr>
<td>---</td>
<td>--------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>13a</td>
<td>Since the change, time that operators spend working together has…</td>
<td></td>
</tr>
<tr>
<td>14a</td>
<td>Since the change, time that operators spend together <strong>informally</strong> has….</td>
<td></td>
</tr>
<tr>
<td>15a</td>
<td>Since the change, the equality in terms and conditions of work for control room and field operators has…</td>
<td></td>
</tr>
<tr>
<td>16a</td>
<td>Since the change, the accuracy of the process information available to operators has…</td>
<td></td>
</tr>
<tr>
<td>17a</td>
<td>Since the change, operator willingness to take risks with the process has…</td>
<td></td>
</tr>
<tr>
<td>18a</td>
<td>Since the change, the quality of technical communication between operators has…</td>
<td></td>
</tr>
<tr>
<td>19a</td>
<td>Since the change, the understanding operators have of what is going on in the plant at any given moment has….</td>
<td></td>
</tr>
<tr>
<td>20a</td>
<td>Since the change, the sharing of information between operators and day staff has….</td>
<td></td>
</tr>
</tbody>
</table>
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