Measurement Good Practice Guide No. 8

Human Factors in Measurement and Calibration

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Abstract: This guide presents practical human factors advice on how to increase effectiveness and efficiency in the measurement and calibration industry. A chapter on 'People' focuses on how to choose the right staff and make the most of their skills via appropriate training courses, supervision and working conditions. A 'Tools' chapter highlights the human factors issues to bear in mind when choosing or developing calibration equipment and software. Finally, a 'Process' chapter identifies influential human factors in such areas as job and process design and the production of reference and procedural documentation. The guide concludes with a series of checklists which can be used to identify your organisation's strengths and weaknesses.

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The objectives of Competing Precisely are:

- to demonstrate the contribution accurate measurement can make towards improving industrial competitiveness and compliance with standards and regulations
- to support the development and application of good measurement practice by providing a practical 'toolkit' that companies can use to improve measurement quality
- to back up awareness raising activities with access to local and national sources of measurement expertise and services.

For more information on Competing Precisely, contact Gareth Francis on 0181-943 6329 (e-mail: competing_precisely@npl.co.uk) or by post at National Physical Laboratory, Teddington, Middlesex, United Kingdom TW11 0LW.

Human Factors in Measurement and Calibration

Contents

1 Executive summary

1.1 Scope of this guide

This guide presents practical human factors advice on how to increase effectiveness and efficiency in the measurement and calibration industry. It is relevant to all managers in such organisations, as well as those who carry out calibration work or are planning to set up a service.

The guide consists of three main chapters as well as supporting sections which provide checklists, case studies, a list of useful contacts and references. The first main chapter focuses on 'People' and how to choose the right staff and make the most of their skills via appropriate training courses, supervision and working conditions. The second considers the 'Tools' used in the calibration industry and highlights human factors issues to bear in mind when choosing or developing calibration equipment and software. Finally, the third main chapter concerning 'Processes' identifies influential human factors in such areas as job and process design and the production of reference and procedural documentation.

It is important to note that while some of the issues raised in this guide may appear to be self-evident, organisations often fail to give them the priority they need. This guide can be used to redress this imbalance. The guide draws relevant current knowledge on ergonomics and human factors into a single volume, and provides practical advice on what to do next to address each issue. A high-level summary of the main recommendations follows.

Main recommendations

People

- Have personnel with practical experience of the work area and good interpersonal skills conduct interviews with potential staff. Also consider aptitude and personality tests to aid selection.
- Guard against any factors (such as excessive time pressures) which may adversely affect staff performance. Remedial action including training courses and/or amendments to working conditions may be needed. Changes to the design of tools, jobs or processes could also be required.
- Ensure staff have the skills and competencies required for their role. If necessary draw up a suitable training and development plan and provide a clear line of management for supervisory guidance.
- If working conditions violate any ergonomic and health and safety issues then alterations to the working environment should also be carried out.

- Apply ergonomic criteria when making equipment purchase decisions or when developing in-house solutions.
- Ensure software for use in calibration and measurement services is 'fit for purpose', that is; accurate, reliable and usable.

- A user-centred approach to the development of new calibration and measurement systems should be taken. In particular it is important to check that users and their tasks are well understood and that wherever possible, prototypes are evaluated with representative end-users.

Process

- Involve staff in the design or review of jobs and address any corresponding concerns that they may have.
- Design work processes to give adequate variety and sufficient breaks. Opportunities for carrying out checking and review activities will also be required.
- Promote information exchange within the organisation. Consider the use of lunchtime discussion meetings or e-mail discussion groups to share insights and experiences.
- Allow staff to concentrate when required and minimise sources of interruption.
- Consider automating any parts of a process which may be prone to error - for example by reducing the need to transcribe rough notes from a display into a 'neat' laboratory notebook. But respect the distinctive strengths of people and machines.
- Experiment with different ways of presenting data. Depending on the nature of the data, and the scales used for display, unexpected values can become clearly visible using graphical displays such as bar graphs.
- Apply ergonomic principles when designing or reviewing a process. Carry out observational studies and redesign where necessary.
- Improve checking strategies where possible, perhaps by introducing checklists or multiple checkers. Provide an appropriate environment and resources to allow checking activities to be carried out carefully and without interruption.
- Review your current reference and procedural material with staff. Follow the general principles of user-centred design by drawing up drafts, having staff evaluate these in their day-to-day work and refining the documentation in light of feedback. Enhancements may include such elements as flow charts and checklists.

2 Introduction

This guide, which is produced as part of a series of measurement good practice guides for the DTI *Competing Precisely* programme, takes as its central theme the impact of human strengths and weaknesses on measurement and calibration activities. An appreciation of human factors or ergonomic issues is crucial if calibration services are to be optimised for effectiveness and efficiency.

Calibration processes and procedures are often complex and time consuming activities whose efficiency can be influenced by a variety of factors. Naturally the overall accuracy of a calibration service will be founded upon the underlying scientific and technical principles. However, the operation of a successful calibration service also depends upon ergonomic or human factors, such as the capabilities of the relevant staff, the design properties of the equipment and software that they rely upon, and the characteristics of the particular task and associated environment. The relationship between these sources of influence is depicted in Figure 1 below.

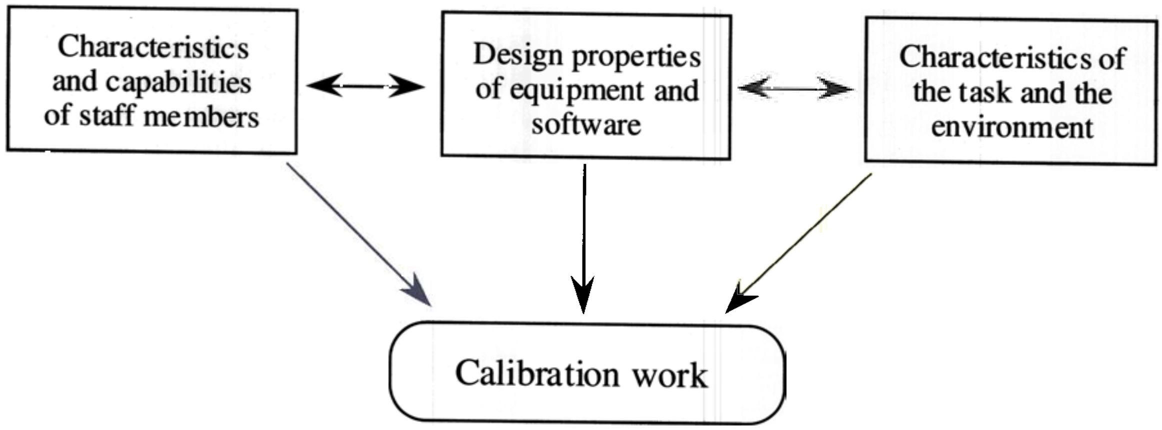

Figure 1. Human factors influencing calibration activities

This guide is divided into three main parts which reflect the categories shown in Figure 1. The first focuses on the **people** involved in calibration work, and the issues to consider to ensure that they are able to carry out their work to the best of their ability. The second part then turns to the **tools,** or the equipment and software that staff must rely on to successfully calibrate artefacts. It highlights issues to guide both the procurement and the development of calibration tools. The third part emphasises the need to ensure that good ergonomic practice is reflected in the calibration **process** of an organisation. It discusses process automation, quality systems and procedures, and offers guidelines to help those organising calibration services achieve a balanced allocation of function between staff and machines. The guide then closes with a summary and checklists of relevant human factors issues as well as some illustrative case studies. The division of the guide into these three main parts compliments the good measurement practice principles promoted under the DTI's *Competing Precisely* and *Valid Analytical Measurement* (VAM) programmes. These highlight the importance of using the right measurements, tools, people and procedures, as well as regular reviews and demonstrable consistency.

3 People

3.1 Introduction

A calibration service provider, as with any other type of organisation, is crucially dependant upon the skills and capabilities of their workforce. For measurement and calibration activities to be performed in a valid and reliable manner staff must be able to work to the best of their ability and dysfunctional pressures need to be avoided. This requires that staff possess appropriate skills, receive relevant training, and that they operate under appropriate working conditions. Each of these aspects is discussed in this chapter. Ensuring that these pre-conditions are met also provides a foundation for the successful implementation of tools and processes, topics that will be addressed later in the guide.

3.2 Choosing the right people

If the demands of a calibration service are to be met it is important to select staff with the right mix of knowledge and aptitudes, as well as the capacity to acquire new skills. Calibration work necessitates high levels of accuracy and reliability, therefore staff should exhibit characteristics such as diligence, attention to detail, and the patience to scrutinise possibly large amounts of numerical information. Such issues are particularly important when checking calibration data and certificates. In this case staff must have the right psychological outlook and personality traits, as well as the necessary practical experience to provide an effective service. Although it is assumed that interviews to select calibration staff will be driven by the need to find people who match this kind of profile there may be a shortfall in some particular skill area and this can be addressed through subsequent training (see section 3.4).

What to do next...

- Ensure that interview panels contain staff who are experienced in the day-to-day nature of the work, as they will know what skills and aptitudes are actually required of new staff.
- Aptitude and personality tests may be used to differentiate between candidates and training courses on interview techniques can also be recommended.
- Professional advice on these matters is available from the Institute of Personnel and Development (see section 8 for contact details).

3.3 Capitalising on the inherent capabilities of staff

By selecting the right staff, meeting their training needs and providing appropriate working conditions the likelihood of making the best use of staff skills and attributes is increased. These inherent capabilities relate to the intellectual, sensory and physical attributes which people possess and are pertinent to the successful accomplishment of tasks. However, the expression of peoples' skills and capabilities can be influenced by various factors which shape human performance and these need to be noted by those involved in calibration activities so that negative influences can be avoided wherever possible.

Factors that may contribute to a loss of efficiency, or even errors in a calibration service include:

- time and resource pressures;
- lack of training or experience;
- ill health;
- personal motivation;
- levels of fatigue and stress;
- team dynamics;
- poor equipment and interface design;
- poor procedures and excessive paperwork.

Previous studies (Thomas et al., 1997) have found that where one or more of these performance shaping factors exerts an influence in an organisation, calibration and certification errors occur. Staff may fail to appreciate particular elements of a situation or they may suffer from memory lapses and mistaken judgements. This can result in a variety of problems such as: transcription and typographical errors, calculation errors and errors due to procedural or technical difficulties. By following the guidance discussed in the rest of this chapter, for example by providing adequate training, support and working conditions, many of the factors which might adversely affect performance can be controlled. However, the last two items in the list above, regarding equipment and interface design and procedural issues, are particularly important and they will be considered in greater detail in the following two chapters of this guide.

What to do next...
➢ Consider the list of performance shaping factors given above. Do any factors regularly exert an influence in your organisation or department?
➢ Explore possible forms of remedial action such as training courses and/or amendments to working conditions.
➢ Changes to the design of tools, jobs or processes may also be required. If so study the advice offered in chapters 4 and 5 of this guide.

3.4 Making sure staff are appropriately trained

Calibration staff should receive appropriate training to equip them for their current job and for any additional challenges that they will face in the future. This latter aspect is particularly important given ongoing developments in test and measurement technology and possible changes in the nature of customer's artefacts. Skill acquisition of this form is likely to be achieved through a combination of organised training courses and the provision of supervisory support.

It is important to realise that even detailed procedures and work instructions are no substitute for training and experience. Indeed this is a recognised principle of the VAM and Competing Precisely programmes. The provision of appropriate training and supervision can also have a number of other positive benefits, as:

- staff will learn to operate by the correct intentions, which will reduce the incidence of errors due to lack of knowledge and skills;

- staff who are well trained are better prepared to meet the challenges of their job and may cope more effectively under conditions of stress and pressure. Staff motivation and confidence should also be boosted by having employers demonstrate a commitment to staff development;
- staff will become more aware of the consequences of their actions and of errors. For example staff who calibrate medical equipment should be familiar with the role played by these devices within the hospital and their importance for the medical procedures concerned. Raising awareness in this manner may prompt greater vigilance, and staff could be less inclined to cut corners or take risks during their work;
- staff should come to appreciate the importance of identifying precise and accurate customer requirements, taking particular care wherever hand-written or faxed correspondence has been supplied for example, as these forms of communication are prone to reading errors and problems of misinterpretation.

However, all training needs to be provided in a timely fashion and followed up by adequate opportunities to put the principles learnt into practice. Where training courses cover the use of equipment and/or software then these systems need to be made available immediately after the training course if staff are to consolidate what they have been taught.

What to do next...
➢ Consider the skills and competencies required for particular roles within your organisation. ➢ Ensure that staff have appropriate knowledge and if not draw up a suitable training and development plan. This will need to be reviewed at regular intervals and updated if the demands of the job or application domain change. ➢ Also ensure that a clear line of management exists and that staff know who to approach for supervisory guidance. ➢ Professional advice on these issues is available from the Institute of Personnel and Development.

3.5 Providing the right working conditions

All measurement and calibration staff must be provided with suitable working conditions. While the equipment used to carry out calibration work is discussed in the tools part of this guide and the process part considers procedural factors, this section refers to key environmental and organisational conditions. Not only are these issues a matter of health and safety (many enforceable by UK law) but the provision of appropriate working conditions directly contributes to calibration efficiency. This especially requires that:

- the layout of workplaces is well planned. The working environment should have sufficient space to accommodate all the equipment, furniture and staff required for the job. Work surfaces should be positioned at a suitable height (to prevent the adoption of poor postural positions and the need to over-reach), and all chairs should be fully adjustable (for height, tilt, backrest angle etc.);
- work requiring repetitive movements or exertion is carefully managed. It is important that staff can enjoy freedom of movement without compromising their

posture and placing undue strain on limbs and muscles. All activities requiring lifting, carrying, pulling or pushing should be carried out with due care and attention in order to avoid fatigue or physical damage;

- suitable lighting is installed. All work settings should feature lighting which is of sufficient intensity and flicker free. If VDU screens are in use then specialised lighting may need to be fitted. It is also important to avoid shiny surfaces in the workplace which may induce glare and reflections. If possible the use of natural daylight to provide uniform ambient lighting should be maximised as this will help to avoid areas of light and shadow;
- the climate in the working environment is appropriate. Staff should work in an environment in which the temperature is suited to the nature of the task. For some measurement and calibration processes this will be clearly stipulated, as in an air conditioned and humidity controlled laboratory. However, where permissible staff should be able to control the local temperature while they work to compensate for fluctuations at different times of the year. As a general rule draughts should also be excluded and radiation and hazardous substance leakage must naturally be guarded against;
- protective clothing or equipment is used. Wherever tasks require it, clothing and equipment which promotes the safety of the workforce should be used. For example this might include hard hats where large force calibration machines are used or eyeglasses where laser-based equipment is being operated;
- sources of noise and vibration are controlled. Excessive noise and vibration can disrupt the flow of tasks and have an adverse effect on staff concentration and performance. Working premises may require sound proofing, or acoustic screens to minimise noise levels. Equipment should also be regularly maintained to prevent the build up of noise and vibration.

What to do next...
➢ Review the list of ergonomic and health and safety issues presented above. If your working conditions violate any of these general principles then alterations to the working environment will be necessary.
➢ Further guidance can be found in various publications produced by the Health and Safety Executive (listed in the references section of this guide) or from local health and safety offices.
➢ The Health and Safety Executive also run an information centre which can offer practical advice (see section 8 for contact details).

4 Tools

4.1 Introduction

In addition to choosing the right people and providing appropriate training and working conditions, efficient calibration processes rely on ensuring that associated equipment and software is 'fit for purpose'. This is reflected in how usable a tool is and how well it matches the needs of users and the needs of the particular task. The primary purpose of this part of the guide is to raise awareness of a range of human factors considerations relating to the 'fitness for purpose' of calibration tools. By reaching an appreciation of the design properties of various technological aids, and ensuring that wherever possible the choice of tools takes users' needs and characteristics into account, calibration efficiency can be enhanced. As all calibration departments have to make choices between items of equipment and software this chapter's main focus will be on human factors guidelines to aid procurement. However, calibration staff may also develop their own tools in-house (typically software) and so the chapter closes with some brief pointers for those developing their own solutions.

4.2 Selecting appropriate equipment and software

4.2.1 General considerations when choosing calibration equipment and software

Calibration processes often make use of a wide variety of electrical, mechanical and digital equipment. However, optimising these processes requires that disruptions to efficiency brought about by a reliance on equipment with sub-optimal features are minimised. In connection this section focuses on relevant human factors principles for those responsible for choosing appropriate equipment.

At a general level it is essential that the purchase and use of calibration equipment is carried out with due regard for the needs of the task, the characteristics of the available operators and the suitability of the operating environment. This can be achieved by considering:

- the characteristics of the task or process - i.e. what are the critical aspects of the task that the equipment must support, and does the equipment match these needs;
- the skills and knowledge of the relevant staff - in particular any training needs that must be met to make best use of the particular item of equipment. Also note that many types of equipment are based on implicit design assumptions regarding the 'typical' psychological, anatomical and anthropometric characteristics (i.e. physical aspects - such as the motion and range of the joints or hands) of intended users. It may also be important to ensure that staff who have special needs can also make optimum use of any equipment purchased;
- the qualities associated with the operating environment - i.e. is there adequate space and appropriate lighting to position equipment and view displays accurately.

Note that it is also of benefit to involve staff who actually carry out the day-to-day work in equipment selection decisions as they are likely to be the most knowledgeable about the demands of the particular task.

In addition to these general points a number of specific observations can be made which relate to properties of the test and measurement equipment commonly used by calibration service providers. These observations have been derived from the literature on ergonomics and human factors (e.g. Murrell, 1979; Salvendy, 1997) and some key points are summarised below:

- when reading relatively static values digital displays are preferable to analogue displays, which are best suited to making comparative and check readings under rapidly changing conditions;
- choose equipment with clear and highly visible controls, and preferably equipment designed so that these controls are grouped by importance, relationship to other controls and frequency of use. The organisation of controls should not depend solely on colour coding as perception of this is influenced by lighting conditions and eyesight complaints. The different controls should also be separated by adequate spacing to prevent accidental activation, a distance of 2-5 cm has been recommended in the human factors literature (Bullinger, Kern and Braun, 1997). However, allowances will need to be made if special items of clothing such as gloves need to be worn. Controls should also be located directly below or adjacent to associated displays. Finally there should be a clear indication of the current mode of operation for any device where this is applicable;
- where possible choose equipment that allows data to be written directly to disk rather than depending on error-prone manual transcription for recording and processing calibration data (see section 5.3.1 on Automation);
- alternatively select equipment which offers a numeric keypad to support manual data entry tasks. This type of activity can also benefit from auditory feedback and devices such as talking wordprocessors and spreadsheets exist. These allow the individual member of staff to receive an auditory verification of the information that they enter;
- choose equipment which makes use of appropriate alarm signals. Should a user's attention need to be drawn to items of equipment under conditions of failure or malfunction then either visual or acoustic signals (or the combination of both) may be used. The key thing is to be able to get an operator's attention even when they are otherwise engaged. But ensure that 'alarm overload' is avoided when things go seriously wrong as this may mask the cause of any problem;
- choose computer hardware that provides an adjustable keyboard to obtain a comfortable typing angle and a tilt and swivel monitor to find a suitable viewing angle free of glare and reflections;
- ensure that wherever possible calibration equipment can output results onto paper, as verification activities such as proof-reading are generally more accurately performed using paper rather than computer displays.

What to do next...
➢ Use the list of bulleted points above to guide equipment purchase decisions and to inform a selection between competing alternatives.
➢ These criteria can also be used to decide if currently owned items of equipment reflect ergonomic best practice.
➢ Further help and advice may be obtained from NPL Usability Services (see section 8).

It is also important to select computer hardware and software which is designed to be usable, that is products which are effective, efficient and satisfying to use in practice. The list which follows (based on qualities stressed by Nielsen, 1993; which are highly regarded in the human factors community) provides a summary of criteria which reflect good usability in interactive systems and software. It can be used to assess competing products, or as a set of guidelines for software developers, and covers:

- *visibility of system status.* Systems should always keep users informed about what is going on, through appropriate feedback within reasonable time;
- *match between system and the real world.* A system should speak the users' language, with words, phrases, and concepts familiar to the user, rather than in system-oriented terms. System messages should follow real-world conventions, making information appear in a natural and logical order;
- *user control and freedom.* Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Also support for undo and redo is important;
- *consistency and standards.* Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions;
- *error prevention.* Even better than good error messages is a careful design which prevents a problem from occurring in the first place;
- *recognition rather than recall.* Make objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate;
- *flexibility and efficiency of use.* Accelerators (often in the form of keyboard shortcuts - unseen by the novice user) may often speed up the interaction for the expert user to such an extent that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions;
- *aesthetic and minimalist design.* Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility;
- *help users recognise, diagnose, and recover from errors.* Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution;
- *help and documentation.* Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and should not be too large.

What to do next...
➢ Use the bulleted list of criteria given above to assess any software products being purchased or developed.
➢ Staff members can use these points as a checklist if they are involved in the assessment of software.
➢ Professional evaluation assistance is also available from NPL Usability Services.

4.2.2 Specific considerations when choosing application software

Various software applications are used within calibration laboratories, including mathematical analysis packages, spreadsheets and wordprocessors. It is naturally important to choose software that matches the requirements of the intended users and their tasks. As well as the general considerations listed in the previous section there are other specific issues which are relevant to the selection of appropriate application software as they have implications for the efficiency of the users of the software. They are:

- *consider interoperability and corporate policy* in the choice of application software, especially if there is a need to exchange data (e.g. wordprocessor files) with other parts of the organisation and possibly contacts outside the organisation;
- *ensure that the application software provides sufficient functionality*, including the ability to integrate with other packages and systems if required and the facilities to layout complex mathematical formula and tables;
- *consider how files can be transferred or stored.* To bridge different packages a common layout language may be required, such as Rich Text Format (RTF). RTF in particular is supported by wordprocessors like Microsoft Word, WordPerfect, FrameMaker, Interleaf and many other packages on UNIX, Apple Macintosh and PC platforms. With reference to databases, there is often a need for a program to transfer data from one database to another or to query a number of databases in different environments. Because of the different formats that data are held in this can be difficult and a universal way of interrogating and altering the data on databases is required. In order to do this, however, a database application must support SQL (for Structured Query Language) and ODBC (for Open DataBase Connectivity);
- *ensure computing terms are clear and understandable.* Making software selection decisions can be a confusing process due to the prevalence of acronyms and jargon in the marketplace. To ensure that your organisation's requirements can be met by the proposed software it is essential that suppliers explain their terms wherever necessary;
- *ensure that the application software provides accurate information.* It is important to determine the 'fitness for purpose' of some commercial packages for integration within calibration systems. This includes spreadsheets and mathematical analysis packages. Not all packages are created equal and the data they provide may differ in precision and accuracy (see Wichman, 1997 for more details).

What to do next...
➢ Carefully consider any application purchase decisions in light of the issues raised above. ➢ Specific help regarding the accuracy of software is available from the Scientific Software Section at the National Physical Laboratory, Teddington, Middlesex. This group has been involved in the production of software qualification reference sets which can be used to provide relative performance measurements for the statistical procedures used in various software packages.

4.2.3 Specific considerations when choosing development software

Calibration services like many other areas of industry are becoming increasingly reliant on computer technology and there is a wide array of hardware and software systems available, each exhibiting different qualities and facilities. For many calibration service providers the choice of hardware will be relatively straightforward - most will employ PC's running the Windows operating system. But choosing appropriate software can be more complex, particularly when selecting a development environment, as choices of this type have implications for in-house development activities (see section 4.3). From the general perspective of staff efficiency and effectiveness there are numerous issues to bear in mind when choosing between alternative development languages. These include: the learning curve for the software, the availability of support, the facilities for debugging, tracing and testing code, the facilities for error and exception handling, the numeric range and precision supported by the language, and whether the software supports the requirements of quality systems. While these issues are important they will not be developed further here, however, a full discussion can be found in the report produced by Harry (1997).

4.3 Developing appropriate equipment and software

For those calibration organisations who develop their own equipment or software much of the guidance given in the earlier sections of this chapter will still apply. The criteria put forward by Nielsen (1993) represent useful guidelines by which a developing system can be evaluated and refined, in addition to providing a basis for assessing commercial offerings. Furthermore, there are a number of international standards (cf. ISO 13407 and ISO 9241) which provide human factors advice of importance to the developers of interactive calibration systems. A thorough treatment of the human factors issues relating to the development of calibration software is outside the scope of this guide. The interested reader is referred to the standards cited above and to the report by Daly-Jones (1997) for further details. However, given the importance of developing usable systems for calibration efficiency, a brief statement of the main principles and activities is appropriate here.

4.3.1 Key principles in user-centred system development

Perhaps the most likely form of in-house development to take place in a calibration laboratory will be the creation or upgrading of software, but note that many of the principles introduced in this sub-section are also relevant to hardware developers.

In order to appropriately equip a calibration service developers of equipment and software should be 'user-centred' in their activities that is: sensitive to the characteristics of their intended users, their particular tasks, and the nature of the environment in which any new tools will be used. According to an emerging international standard (ISO/DIS 13407 - 'Human-centred design processes for interactive systems') there are four essential user-centred design activities which can be undertaken to ensure that a system will be usable. These are:

- understand and specify the context in which the system will be used (who the users are, what their tasks are and what characterises their environment);
- specify the user and organisational requirements for the system;
- produce designs and prototypes of the system;
- carry out assessments of the system with representative users and tasks.

These activities are carried out in an iterative fashion as depicted in Figure 2, with the cycle being repeated until the system is deemed to reflect the identified user requirements and thus provides a solution which can be used effectively, efficiently and with satisfaction (in line with the ISO 9241-11 definition of a usable system).

Although user-centred design represents a valuable strategy for the developers of calibration systems and software only a very brief overview of the key principles and activities has been possible here. A more complete description can be obtained from the sources cited at the start of this section.

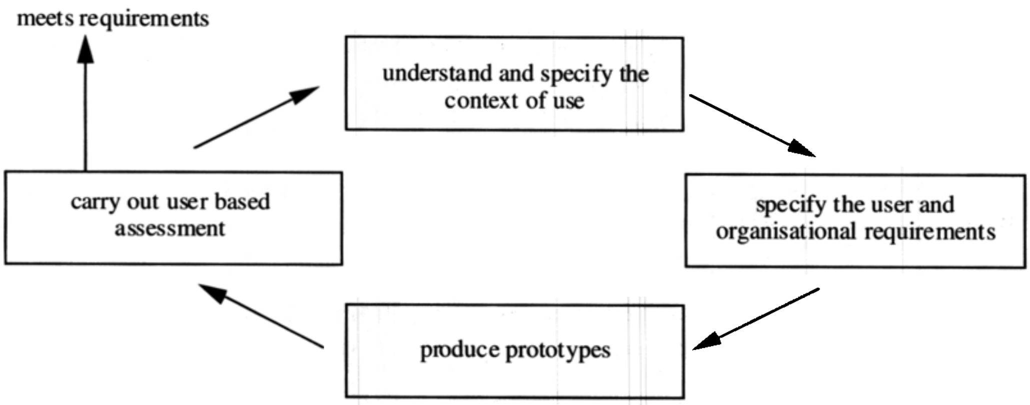

Figure 2. Key user-centred design activities

What to do next...
➢ Developers of new calibration and measurement systems should review their practices in light of the principles shown above.
➢ It is important to check that users and their tasks are sufficiently well understood and that wherever possible prototypes are evaluated with real users.
➢ Consultative help and guidance in this area can be obtained from NPL's Usability Services (see section 8 for details).

5 Process

5.1 Introduction

Measurement and calibration processes can take up the whole of a person's job, or they may be integrated with other activities unrelated to the measurement work. There are a number of considerations relating to how staff responsibilities are organised, which can have direct implications for the frequency of human error. Considerations include:

- frequency and duration with which an individual carries out particular measurement/calibration processes;
- design of the measurement/calibration process in terms of the order in which parts of the process are carried out, etc.;
- allocation of activity between individuals and their co-workers and machines;
- how checking of results is carried out.

These considerations have implications for the design of calibration jobs, processes and procedural documentation. These three aspects form the focus of this chapter.

5.2 Job design

In general, job satisfaction will be greater where one individual is responsible for a series of related tasks - for example, taking responsibility for a calibration from the beginning to the end of the process. But the complexity of the process needs to match the skills and aspirations of the operator - responsibility for a process more complex than the operator can cope with, or for what he or she sees as too repetitive, lengthy or mundane will be de-motivating. To avoid this the following points should be noted:

- appropriate allocation of processes, or parts of a process, between co-workers is crucial in terms of staff motivation. Resentment and consequent de-motivation and risk of error can build up if one member of staff perceives others to have 'better' work than themselves;
- in terms of integrating measurement and calibration work with other activities, the relative attributes of the different activities need to be considered. If the other activities are perceived as more interesting, more stressful, or more demanding, then the measurement tasks may suffer in terms of the time and attention devoted to them. It is also important that staff responsibilities are sensibly demarcated. Scientific staff should not spend too much of their time on the contractual, procedural and financial elements of the business at the expense of their technical work. If possible more of this kind of work should be carried out by support staff thus allowing calibration staff to concentrate more fully on the technical rather than contractual challenges posed by their work;
- both jobs and the working environment need to be designed so that operators and checkers are allowed to concentrate, but are able to avoid long periods of work which result in fatigue. In general, most people find it difficult to concentrate intensively for individual periods of more than half an hour to one hour;
- provision should be made for adequate feedback mechanisms and opportunities for checking. Fast and appropriate feedback is necessary for an operator to identify and correct their own errors soon after they arise. This may entail the use of computer

systems which provide indicators when data exceed the expected norms or alternatively, checking procedures to be carried out by one or more members of the calibration laboratory;

- where last-minute or urgent jobs are a feature of a person's workload, this needs to be planned for in advance. By their nature, each occurrence of such a job will be unexpected, but the benefits of allowing contingency for such eventualities will, in general, be outweighed by the fact that jobs are not rushed or slotted in at the last minute, both of which may contribute to increased risk of error;

communication between staff responsible for different processes within the same organisation is crucial. Coordination of calibration activity at a high level will ensure that the sharing of experience, expertise, processes, equipment, and data can be done smoothly and without duplication of effort. It is also important because whilst one person may have responsibility for a particular calibration, others need to be involved so that they can carry on whenever the responsible individual is absent for a period of time.

In some cases a redesign of working conditions and practices may be required to combat negative factors which are of a serious or persistent nature such as excessive work load or time pressures. In this case it is necessary to alter the job design to allow more time and flexibility in working practices. But note that such changes should be carried out in full consultation with those affected.

What to do next...

➢ Include all relevant staff in the design or review of jobs and identify their attitudes towards their work. Occasional one-to-one meetings with staff where such issues are discussed are useful, and then, if a problem is identified, address the reasons why.

➢ Problems may include lack of training, time and resource pressures, or the need to 're-shuffle' jobs and responsibilities within a team.

➢ Adequate provision for breaks during work along with opportunities for checking will also be required.

➢ Finally, promote information exchange within your organisation so that insights and experiences can be shared between different staff. Consider the use of lunchtime discussion meetings or e-mail discussion groups and mailing lists for this.

5.3 Process design

When designing processes, as opposed to the jobs which include those processes, there is often less freedom of choice. Sequences of events and the ways in which they are carried out will be governed by the nature of the scientific process, by relevant standards and guidelines, and by practical constraints. However, where there are elements of choice, the role of the human operator needs to be defined with reference to relevant human capabilities - and weaknesses.

In particular, it is important to pay attention to all steps where people are involved in the entering, recording or interpretation of data. Also note that:

- allowing for interrupt-free data entry will reduce the scope for errors due to 'loss of place';

keeping the number of steps of data transfer to an absolute minimum will reduce the scope for transcription error;

- displaying data graphically can offer a good means of showing up deviant data values.

What to do next...
➢ Allow staff to concentrate on entering data perhaps via the use of answering services, 'do not disturb' notices on doors or 'quiet' times of day to indicate that interruptions are not welcome. ➢ Also analyse the measurement process, looking at steps which involve a person or machine transferring data from one form to another. Ask whether any of the steps could be consolidated - for example by reducing the need to transcribe rough notes from a display into a 'neat' notebook. ➢ Finally, experiment with different ways of presenting data - spreadsheets are useful for this. Depending on the nature of the data, and the scales used for display, unexpected values can become clearly visible using graphical displays such as bar graphs.

Furthermore, process design should also conform to relevant principles of good design (see section 4.2.1), including:

- providing feedback - **visibility** of the status of the parts of the process - so that operators can see what is happening and make corrections if necessary;
- designing the process to **match the real world** - using understandable language in documentation and instruction, making sure that process requirements match the skills and capabilities of the operators and their environment (for example, avoiding the use of audible warnings for deaf operators or in noisy environments);
- allowing the user to be, as far as is possible, in **control** of the pace of the process so that they can work in their own way and cope with interruption or urgency;
- allowing, where possible, the user to **'undo'** or reverse actions that they may have performed by mistake, so that process errors do not result in lengthy fixes or data errors;
- provide **consistency** in terms of the placement of items and equipment, ways of carrying out similar functions etc.;
- providing access to **help** when an operator needs it.

What to do next...
➢ Look at the design of your process. Review the principles of good design above, thinking about each point and whether your process conforms to it. Ask the operators if they agree. ➢ Also address the issues explicitly whilst working with and observing an operator who is conducting an actual test or measurement using the process. If this shows some areas where there are problems, apply any 'quick fixes' and think about re-designing the process or supporting equipment, using the principles outlined in section 4.3.

5.3.1 Automation

Only by automating parts of a process can human error be eliminated from those parts of that process. The risk of some instances of error such as transcription or calculation errors can be minimised through the use of computer systems in place of manual labour. Automation may also contribute to a reduction in the amount of time required for checking activities.

However, automation should not be seen as an automatic route to human error reduction - whilst computerised or mechanised activities will reduce the scope for human slips and mistakes, they increase the potential for more systematic errors embedded in code, and do nothing to reduce errors in human data entry or understanding of output. Indeed, in some cases, over-reliance on 'the computer', as well as providing something to 'blame', may result in a false sense of security and reduced vigilance.

It is therefore important that there is a clear and sensible division of labour between the human and the machine. Some types of activity are, in general, better suited to humans, and others to machines (Helander, Landauer and Prabhu, 1997; Thomas et al., 1997; Salvendy, 1997). For example:

- humans are generally better at creative and design processes;
- humans are generally better than machines at responding flexibly to novel situations;
- humans have a limited information processing capacity, whereas machines can gather and process more information in a given time;
- humans respond more slowly than machines to simple stimuli;
- humans are better at complex pattern recognition;
- humans can identify unusual error situations that a system has not been programmed to detect;
- humans are better at discriminating masked, overlapping and noisy information;
- humans can be unreliable in terms of data recall and transcription.

However, the desirable division of labour changes rapidly with the evolution of new automated systems, with the type of software in use by an organisation, and in accordance with other considerations in place during process design. The practice of splitting tasks into solely 'human' vs. 'computer' is declining - many scenarios now stress a 'partnership' where an operator works with equipment and software to produce a joint output. Thus an approach whereby activities are allocated on a case by case basis according to the needs of each process, bearing in mind the above principles but not using them as hard and fast rules, is preferable.

What to do next...
➢ Again examine the design of your process, noting which steps are carried out (or due to be carried out if the process is being redesigned) by the operator, by the technology, or by a dialogue between both. ➢ Go through the bullet points above, asking whether the allocation of each step agrees with these principles.

5.3.2 Checking processes

Even where part of the process is automated, the occurrence of errors must be guarded against. There will, therefore, always be a need to check the output of calibration activities. However, a previous investigation (Thomas et al., 1997) indicates that checking itself can be subject to human error and that where humans are responsible for particular tasks, errors may always be present.

The types of checking strategies applied are very much dependent on the nature of the calibration and its environment. Some checking methods are particularly suited to specific types of calibrations, whereas others are more generic and can be used in a variety of calibration services. The most effective checking methods are not necessarily the most expensive in terms of cost. In general one should:

- make use of checklists, more than one checker, and known information (such as referring back to the original data). Other methods such as carrying out spot checks should only be used to augment the checking process;
- carry out checks soon after the measurements are completed while the context is still fresh in the minds of the calibration staff. This may help not only in the verification of the figures but also in the validity of the data itself;
- avoid time constraints which may subconsciously make staff try to perform the checking more quickly and with a consequential loss in effectiveness. Given the criticality of checking work serious consideration should be given to the design of jobs that allow for 'unpressurised' checking;
- carefully consider corrective actions when an error occurs - increasing the number of checks may not be effective and may be detrimental because of 'diffusion of responsibility' and hence reduced vigilance by individual members of staff;
- assess the balance of checks made - whether enough are being made against the actual data recording, rather than on subsequent transcription and manipulation of figures;
- encourage staff to accept that human errors will occur - no matter how senior or experienced the calibrator/checker is;
- organise job roles and allocate checking tasks to ensure that the checker will not be inhibited in any way, consciously or subconsciously, from finding and reporting errors - for example because they have to check the work of a person who occupies a more senior position;
- carefully evaluate the efficiency of different checking procedures - collecting objective and accurate data to determine true cost and effectiveness.

To completely eliminate all errors either by preventing their occurrence or by trapping them during checking is an extremely expensive and possibly unattainable goal. Rather the aim should be to reduce the rates and impact of errors to an absolute minimum, achieving a balance of cost-effectiveness, speed of service and quality of output.

What to do next...

- ➢ Review your strategies for checking, in light of the issues identified above. Discuss possible areas for improvement with the staff who will actually carry out the checking.
- ➢ If not already in use you may consider introducing such things as checklists or multiple checkers.
- ➢ Ensure staff appreciate the importance of checking. Provide an appropriate environment and resources to allow checking activities to be carried out carefully and without interruption.

5.4 Reference and procedural material

All measurement and calibration processes will be governed by documentation of some kind. There will almost certainly be working procedures to follow, standards to refer to, and a whole host of other background documents which apply to a particular working environment and process.

Much of the documentation will not be read by those to whom it applies. This is particularly the case where there are conflicting, lengthy, and perhaps partly irrelevant sources of information. In order to promote the usefulness of reference and procedural material:

- all documents should be clear, concise, and provide only relevant information. Documents may need to be tailored extensively to deal with different processes and circumstances;
- a user-centred approach to the development of procedures should be adopted. User requirements and the way people actually work in practice - as well as how good practice dictates that they should be working - need to be analysed thoroughly as part of procedure design. The operators themselves need to have recognised time to evaluate how the procedures actually apply in practice for their own work, and to be able to get those procedures changed if necessary. This approach is also specified in ISO 13407 (draft on 'Human-centred design processes for interactive systems');

  use flow charts, which then refer to forms and checklists containing prompts for all the necessary actions, to help make process documentation easier to follow correctly. The potential advantage of such an approach is that prompts for actions are raised at the appropriate points in time. More general information should still be made available for reference purposes but if the flow chart is followed, then the key procedural requirements should still be met;

  use checklists to reduce the apparent complexity and enable staff who are familiar with procedures see at a glance what actions are required of them. They are also able to keep a record themselves of what has been done and where they are in a process - especially valuable where staff experience unavoidable interruptions;
- for small jobs, consider modifying procedures in order to reduce the proportion of the job spent on administrative overheads.

What to do next...
➢ Review your current reference and procedural material, ideally by canvassing staff for feedback on possible improvements that could be made. ➢ Consider areas where staff may benefit from the inclusion of elements like flow charts and checklists and then follow the general principles of user-centred design. For example draw up drafts, have staff evaluate these in their day-to-day work and refine the documentation in light of their feedback.

6 Summary and checklists

The importance of integrating people, tools and processes

This guide has presented human factors advice relating to the people, tools and processes used in the measurement and calibration industry. The 'People' chapter focused on the importance of choosing the right people and making the most of their skills via appropriate training courses, supervision and working conditions. The 'Tools' chapter highlighted human factors issues to bear in mind when choosing or developing calibration equipment and software. Finally, the 'Process' chapter identified influential human factors in such areas as job and process design and the production of reference and procedural documentation.

The logical division of this guide with reference to people, tools and process was primarily used to aid clarity. In practice however, the overall effectiveness of measurement and calibration services will depend upon each of these aspects and, importantly, the interaction between them. It is therefore crucial to consider the relevance of all these issues. To help, the remainder of this chapter provides a series of checklists which can be used for assessment purposes in your own organisation and as a summary reference of the key points made throughout this guide.

Checklists

The checklists given in the following pages operationalise the recommendations presented in this guide. They are structured as a series of statements under the three categories of People, Tools and Process. The reader is asked to respond to the statements by indicating:

- the priority they, and their service or organisation, ascribe to the highlighted issue;
- the extent of their knowledge regarding the particular issue;
- the number of experienced problems which could be attributed to the issue.

All responses can be entered into the central columns of the checklist tables as a rating using the terms: 'High', 'Medium' or 'Low'. A worked example is given below. This shows that the particular issue (in this case staff training): is a *high* priority for the organisation, is something which a *medium* amount is known about, and is an issue which has led to only a *low* number of problems. Note that the column headed 'N/A' may be used where an issue is felt to be irrelevant and the final column in the tables provides a pointer to the relevant sections of this guide for reference purposes.

People	Priority	Knowledge	Problem	N/A	Reference and Action
Where necessary all staff are provided with access to relevant and suitably organised training courses.	High	Medium	Low	-	See Section 3.4 - 'Making sure staff are appropriately trained'

Table 1. Extract from a completed checklist

This approach encourages the reader to focus on the issues and determine for themselves the associated priority, knowledge and problem levels. When reviewing completed checklists it is important to prioritise those areas which pose a risk to the organisation's activities. Particular attention should be paid to issues which are considered to be a high priority, yet poorly understood (indicated by a '*low*' rating in the knowledge column) and likely to lead to problems (indicated by a '*medium*' or '*high*' rating in the problem column). In such cases it would be advisable to follow the recommendations provided in the guide or seek further help from one of the organisations listed in section 8.

The purpose of these checklists is not to dictate how a calibration service should be run. Rather it is to raise awareness of the range of human factors issues that can impinge on calibration efficiency and to indicate how these issues can be addressed.

If the use of these checklists reveals particular areas of concern then NPL may be able to offer further help. In such cases send completed checklists to: Andrew Harry, NPL Usability Services, National Physical Laboratory, Teddington, Middlesex, TW11 0LW, or by fax to: 0181-977 7091.

6.2.1 People checklist

For calibration activities to be performed in a valid and reliable manner staff must possess appropriate skills and training. They must also operate under appropriate working conditions so that their inherent capabilities are called upon and dysfunctional pressures are avoided.

People	Priority	Knowledge	Problem	N/A	Reference and Action
We only select staff with appropriate knowledge, skills and aptitudes.					See Section 3.2 - 'Choosing the right people'
Factors which may have an adverse affect on staff performance are guarded against.					See Section 3.3 - 'Capitalising on the inherent capabilities of staff'
Where necessary all staff are provided with access to relevant and suitably organised training courses.					See Section 3.4 - 'Making sure staff are appropriately trained'
Where necessary all staff are provided with supervisory support and guidance.					See Section 3.4
All training is timely with new systems immediately available to support the consolidation and retention of information.					See Section 3.4
The layout of workplaces is well planned.					See Section 3.5 - 'Providing the right working conditions'
All work requiring repetitive movements or exertion is carefully managed.					See Section 3.5
Suitable lighting is installed (e.g. for VDU use).					See Section 3.5
The climate (i.e. temperature) in the working environment is appropriate to the task.					See Section 3.5
Protective clothing or equipment is used wherever necessary.					See Section 3.5
Sources of noise and vibration are controlled.					See Section 3.5

Table 2. Checklist of human factors issues relating to people

6.2.2 Tools checklist

Efficient calibration processes rely on ensuring that associated equipment and software is 'fit for purpose'. This is reflected in the quality of the interaction between an operator and an artefact, i.e. how usable a tool is and how well it matches the needs of users and the characteristics of the particular task domain.

Tools	Priority	Knowledge	Problem	N/A	Reference
Purchase and use of calibration equipment is based on task, staff and environment characteristics.					See Section 4.2.1 - 'General considerations when choosing calibration equipment and software'
Staff who actually carry out the work are involved in equipment selection decisions.					See Section 4.2.1
Items of equipment with appropriate displays (e.g. digital or analogue, depending on the task) are chosen.					See Section 4.2.1
Items of equipment with clear and highly visible controls are chosen.					See Section 4.2.1
Where available items of equipment which allow data to be written directly to disk are chosen.					See Section 4.2.1
Equipment that can provide suitable alarms/alerts and output paper results for checking is chosen.					See Section 4.2.1
Computing equipment with adjustable keyboards and monitors and numeric keypads is chosen.					See Section 4.2.1
Usability criteria apply when selecting hardware and software.					See Section 4.2.1
Issues like interoperability, functionality and accuracy are considered when choosing application software.					See Section 4.2.2 'Specific considerations when choosing application software'
Issues like learning curves and error handling are considered when choosing development software.					See Section 4.2.3 'Specific considerations when choosing development software'
Systems and software developed in-house reflect the principles of user-centred design.					See Section 4.3 - 'Developing appropriate software and equipment'

Table 3. Checklist of human factors issues relating to tools

6.2.3 Process checklist

Accuracy and validity during measurement and calibration work can depend upon the design of calibration jobs, calibration processes and procedural documentation.

Process	Priority	Knowledge	Problem	N/A	Reference
An appropriate allocation of processes (or parts of) is achieved between staff.					See Section 5.2 - 'Job design'
Measurement/calibration work and other duties (e.g. financial, contractual) are balanced. Staff responsibilities are clearly and sensibly demarcated.					See Section 5.2
Operators/checkers can concentrate and receive suitable feedback, but avoid excessive workloads resulting in fatigue.					See Section 5.2
Contingency for urgent jobs is available to avoid excessive time and stress pressures.					See Section 5.2
Communication is supported, enabling staff to cover each other. Experiences & problems can be shared (e-mail lists etc.).					See Section 5.2
Changes to working practices are carried out following consultation with all staff to be affected.					See Section 5.2
Interrupt-free data entry is allowed. Manual data transfer steps are minimised.					See Section 5.3 - 'Process design'
Graphical means of displaying data are utilised (to show deviant values).					See Section 5.3
Basic design principles (e.g. consistency, control, match to the real world) are reflected in processes.					See Section 5.3
The labour division between machines and staff reflects human factors advice.					See Section 5.3.1 - 'Automation'
Effective checking strategies (checklists, multiple checkers etc.) are used at key points in the process.					See Section 5.3.2 - 'Checking processes'
Checking is carried out promptly and without undue time pressures.					See Section 5.3.2
A user-centred approach to the creation of supporting documentation (involving drafts and trials) is taken.					See Section 5.4 - 'Reference and procedural material'
Flowcharts and checklists are used.					See Section 5.4

Table 4. Checklist of human factors issues relating to processes

7 Examples and case studies

This section illustrates how some of the issues discussed earlier in the guide have been addressed by two calibration and measurement departments. This provides a useful summary of the lessons learnt within other organisations. The first case study covers a range of human factors issues, based on the checklists presented in the previous section, while the second focuses on the application of user-centred design principles to the development of new calibration tools.

7.1 General case study

This case study relates to a calibration department that is involved in developing and maintaining primary standards for dimensional, wavelength and optical metrology, as well as developing new and improved calibration and testing methods. The organisation applies these standards in support of a variety of users, including those from the following sectors: industry, science, health and safety, environmental protection, quality assurance, and statutory and regulatory bodies.

As with all calibration and measurement organisations the accuracy of measurements is critical and there is a growing awareness of the need to look at ways of reducing error rates. In the past errors have been found to be caused or exacerbated by environmental and human factors. The organisation has already taken steps via its quality system and checking procedures to combat such errors. Records are kept as errors occur and these are regularly reviewed with actions put in place to help prevent the same type of error occurring in the future. In many cases the remedial action taken by the organisation reflects the recommendations put forward in this guide.

In order to ensure that human factors considerations are fully taken into account staff within the laboratory reviewed the checklists and content of this guide. Generally speaking the organisation felt that error rates were low and that current practices were satisfactory. Use of the checklists, however, did raise a number of points of concern which suggested that not all of the factors which could adversely affect staff performance were being guarded against.

For example, in this particular department each calibration service tends to be run by a single individual who has both set up the service and is responsible for carrying out the tests. If this person falls ill or is under pressure then it is often not possible to bring in another member of staff with the necessary expertise and understanding to maintain the service. An additional area of concern relates to the balance between measurement and calibration work and other duties. The changing nature of the business over recent years has meant that calibration staff also have to take on a lot of management and organisational support work in addition to carrying out calibrations. In many cases having to do this extra work on top of an already full workload is demotivating as these additional duties can take as much time as the calibrations themselves. These factors combine to place undue time pressures and stress on staff, causing concern that there is no contingency for urgent jobs. Steps to recruit additional staff to ease the resource pressures and allow scientific staff more time to concentrate on the actual calibration and measurement work are now being taken.

There was also a clear need to reconsider checking strategies within the department as most of the checking was currently being carried out by the head of the department as the main signatory for work. Since this person has many other activities he was often hard to find when required and was also under significant time pressures himself. As a potential solution to this predicament the use of multiple checkers and checklists is now being considered.

Working through the checklists in this guide also confirmed that a user-centred approach had not been used in the creation of supporting documentation. While the actual measurement procedures had been written by the people who carried out the calibrations, and therefore reflected their needs, this did not apply to the administrative documentation which had been developed on a more ad-hoc basis. In the future there was an intention to ensure that all supporting information was developed by those most directly affected and subjected to rounds of review and iteration.

On a more positive note the staff who carry out the calibrations are involved in the development of services and the selection of equipment. This means that only items of equipment with appropriate functionality and design properties are chosen.

7.2 Tool development case study

This case study illustrates the value in taking a user-centred approach to the design and implementation of new calibration systems and software. It shows how a new system was evaluated and refined with representative staff so as to ensure that the final system reflected ergonomic best practice.

The case study stems from the requirement of a thermal metrology laboratory for a system to automate thermal conductivity and emissivity measurements. To this end, software to control the operation of guarded hot plates was commissioned. This system had to monitor and record data from the hotplates, which were used to subject artefacts to a series of tests at predefined temperatures, in order to determine their thermal conductivity or emissivity at different temperatures. The software was to provide regularly updated information on the artefact during the test and a results summary and calibration certificate at the end of each test.

In line with the basic principles of user-centred design (see section 4.3.1), information regarding the context in which the new system would be used was collected. This was to inform the designers of the new system of the characteristics of the intended users, their tasks, and their environment. For example the initial context gathering exercise indicated: that the system would be operated by both novice and expert staff, that one person would be responsible for running an entire test, and that on occasions they could be interrupted by telephone calls. It was also known that the system was to be housed near noisy laboratory equipment.

Sensitive to the various contextual issues a series of evaluations were carried out in order to obtain feedback on the developing system. These were carried out in the laboratory itself and involved representative staff being video-taped whilst they used a prototype of the system to perform set but realistic tasks. During this process observers took notes of any difficulties or problems that the users experienced.

By examining the video tapes, along with interview comments made by the users both before and after the evaluation sessions, the development team were able to determine the type and range of problems associated with the system. This raised concerns regarding the manner of data input, style of interaction, feedback from the system, and how users should navigate within the system. Some of the specific problems identified are listed below, for example:

- it was not clear from the visual display which particular hotplate was being monitored at any one time;
- there was no undo or back option available. If mistakes were made it was not easy to correct them, and the user was often forced to return to the opening screen to repeat his or her steps again;
- when entering numeric data users tended to enter it in columns, entering all the data for one column before going on to the next. However, the tabbing on the system had been set to tab across rows making it difficult for users to do this easily and so slowing down the input process;
- there was an inconsistent approach to the layout and use of the various buttons employed by the system. Some buttons bearing the same name performed completely different actions on different screens and were laid out in a non-standard way making it difficult for the users to remember where to find them and what they were for.

By employing some of the key user-centred design activities and an iterative cycle of design and evaluation the problems described above were eliminated during development. This resulted in a final version of the software which proved to be more effective and more suited to the needs of the calibration staff than would otherwise have been the case. The staff using the software have subsequently expressed their satisfaction with the system.

8 Useful contacts

This section provides contact details for the organisations listed in this guide who can provide further practical support and advice. They are:

Health and Safety Executive
Information Centre
Broad Lane
Sheffield, S3 7HQ
Tel: 0541-545 500
Fax: 0114-289 2333
Web: http://www.open.gov.uk/hse/hsehome.htm

Institute of Personnel and Development
IPD house
315 Camp Road
Wimbledon, SW19 4UX
Tel: 0181-971 9000
Fax: 0181-263 3333
Web: http://www.ipd.co.uk/

National Physical Laboratory
Teddington
Middlesex, TW11 0LW
Tel: 0181-943 6880 (NPL Helpline)
Fax: 0181-943 6458
Web: http://www.npl.co.uk/

NPL Usability Services
Tel: 0181-943 7019
Fax: 0181-977 7091
E.Mail: usability@npl.co.uk
Web: http://www.npl.co.uk/npl/sections/us

NPL Scientifc Software Section
Tel: 0181-943 7050
Fax: 0181-977 7091
E.Mail: bernard.chorley@npl.co.uk
Web: http://www.npl.co.uk/npl/cise/sss/

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