CHAPTER 42

Human Factors Audit

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When we audit an entity, we perform an examination of it. Dictionaries typically emphasize official examinations of (financial) accounts, reflecting the accounting origin of the term. Accounting texts go further: for example, "testing and checking the records of an enterprise to be certain that acceptable policies and practices have been consistently followed" (Carson and Carlson 1977, p. 2). In the human factors field, the term is broadened to include nonfinancial entities, but it remains faithful to the concepts of checking, acceptable policies/practices, and consistency.

Human factors audits can be applied, as can human factors itself, to both products and processes. Both applications have much in common, as any process can be considered as a product of a design procedure, but this chapter emphasizes process audits because product evaluation is covered in detail in Chapter 49. Product usability audits have their own history (e.g., Malde 1992), which is best accessed through the product design and evaluation literature (e.g., McClelland 1990).

A second point needs to be made about the scope of this chapter: the role of checklists. As will be seen, checklists have assumed importance as techniques for conducting human factors audits. They can also be used alone as evaluation devices, in applications as diverse as VDT workplaces (Cakir et al. 1980), and risk factor assessment (Keyserling et al. 1992). Hence, the structure and use of checklists will be covered in some detail independently of their use as an auditing technique.

1. THE NEED FOR AUDITING HUMAN FACTORS

Human factors or ergonomics programs have become a permanent feature of many companies, with typical examples shown in Alexander and Pulat (1985). Like any other function, human factors/ergonomics needs tools to measure its effectiveness. Earlier, when human factors operated through individual projects, evaluation could take place on a project-by-project basis. Thus, the interventions to improve apparel-sewing workplaces described by Drury and Wick (1984) could be evaluated to show changes in productivity and reductions in cumulative trauma disorder causal factors. Similarly, Hasslequist (1981) showed productivity, quality, safety, and job satisfaction following human factors interventions in a computer-component assembly line. In both cases, the objectives of the intervention were used to establish appropriate measures for the evaluation.

Ergonomics/human factors, however, is no longer confined to operating in a project mode. Increasingly, the establishment of a permanent function within an industry has meant that ergonomics is more closely related to the strategic objectives of the company. As Drury et al. (1989) have observed, this development requires measurement methodologies that also operate at the strategic level. For example, as a human factors group becomes more involved in strategic decisions about identifying and choosing the projects it performs, evaluation of the individual projects is less revealing. All projects performed could have a positive impact, but the group could still have achieved more with a more astute choice of projects. It could conceivably have had a more beneficial impact on the company's strategic objectives by stopping all projects for a period to concentrate on training the management, workforce, and engineering staff to make more use of ergonomics.

Such changes in the structure of the ergonomics/human factors profession indeed demand different evaluation methodologies. A powerful network of individuals, for example, who can, and do, call for human factors input in a timely manner can help an enterprise more than a number of individually successful project outcomes. Audit programs are one of the ways in which such evaluations can be made, allowing a company to focus its human factors resources most effectively. They can also be used in a prospective, rather than retrospective, manner to help quantify the needs of the company for ergonomics/human factors. Finally, they can be used to determine which divisions, plants, departments, or even product lines are in most need of ergonomics input.

2. DESIGN REQUIREMENTS FOR AUDIT SYSTEMS

Returning to the definition of an audit, the emphasis is on checking, acceptable policies, and consistency. The aim is to provide a fair representation of the business for use by third parties. A typical audit by a certified public accountant would comprise the following steps (adapted from Koli 1994):

1. *Diagnostic investigation:* description of the business and highlighting of areas requiring increased care and high risk
2. *Test for transaction:* trace samples of transactions grouped by major area and evaluate
3. *Test of balances:* analyze content
4. *Formation of opinion:* communicate judgment in an audit report

Such a procedure can also form a logical basis for human factors audits. The first step chooses the areas of study, the second samples the system, the third analyzes these samples, and the final step produces an audit report. These define the broad issues in human factors audit design:

1. *How to sample the system:* how many samples and how these are distributed across the system
2. *What to sample:* specific factors to be measured, from biomechanical to organizational
3. *How to evaluate the sample:* what standards, good practices, or ergonomic principles to use for comparison
4. *How to communicate the results:* techniques for summarizing the findings, how far separate findings can be combined

A suitable audit system needs to address all of these issues (see Section 3), but some overriding design requirements must first be specified.

2.1. Breadth, Depth, and Application Time

Ideally, an audit system would be broad enough to cover any task in any industry, would provide highly detailed analysis and recommendations, and would be applied rapidly. Unfortunately, the three variables of breadth, depth, and application time are likely to trade off in a practical system. Thus a thermal audit (Parsons 1992) sacrifices breadth to provide considerable depth based on the heat balance equation but requires measurement of seven variables. Some can be obtained rapidly (air temperature, relative humidity), but some take longer (clothing insulation value, metabolic rate). Conversely, structured interviews with participants in an ergonomics program (Drury 1990a) can be broad and rapid but quite deficient in depth.

At the level of audit instruments such as questionnaires or checklists, there are comprehensive surveys such as the position analysis questionnaire (McCormick 1979), the Arbeitswissenschaftliche Erhebungsverfahren zur Tätikgkeitsanalyse (AET) (Rohmert and Landau 1989), which takes two to three hours to complete, or the simpler work analysis checklist (Pulat 1992). Alternatively, there are simple single-page checklists such as the ergonomics—working position—sitting Checklist (SHARE 1990), which can be completed in a few minutes.

Analysis and reporting can range in depth from merely tabulating the number of ergonomic standards violated to expert systems that provide prescriptive interventions (Ayoub and Mital 1989).

Most methodologies fall between the various extremes given above, but the goal of an audit system with an optimum trade-off between breadth, depth and time is probably not realizable. A better practical course would be to select several instruments and use them together to provide the specific breadth and depth required for a particular application.

2.2 Use of Standards

The human factors/ergonomics profession has many standards and good practice recommendations. These differ by country (ANSI, BSI, DIN), although commonality is increasing through joint standards such as those of the International Standards Organization (ISO). Some standards are quantitative, such as heights for school furniture (BSI 1965), sizes of characters or a VDT screen (ANSI/HFS-100), and occupational exposure to noise. Other standards are more general in nature, particularly those that involve management actions to prevent or alleviate problems, such as the OSHA guidelines for meat-packing plants (OSHA 1990). Generally, standards are more likely to exist for simple tasks and environmental stressors and are hardly to be expected for the complex cognitive activities with which human factors predictions increasingly deal. Where standards exist, they can represent unequivocal elements of audit procedures, as a workplace which does not meet these standards is in a position of legal violation. A human factors program that tolerates such legal exposure should clearly be held accountable in any audit.

However, merely meeting legal requirements is an insufficient test of the quality of ergonomics/human factors efforts. Many legal requirements are arbitrary or outdated, such as weight limits for manual materials handling in some countries. Additionally, other aspects of a job with high ergonomic importance may not be covered by standards, such presence of multiple stressors, work in restricted spaces resulting in awkward postures, or highly repetitive upper extremity motions. Finally, there are many human factors good practices that are not the subject of legal standards. Examples are the NIOSH lifting equation (Waters et al. 1993), the Illuminating Engineering Society (IES) codes (1993), and the zones of thermal comfort defined by ASHRAE (1989) or Fanger (1970). In some cases, standards are available in a different jurisdiction from that being audited. As an example, the military standard MIL-1472D (DOD 1989) provides detailed standards for control and display design that are equally appropriate to process controls in manufacturing industry but have no legal weight there.

Standards, in the legal sense, are a particularly reactive phenomenon. It may take many years (any many injuries and accidents) before a standard is found necessary and agreed upon. The NIOSH lifting equation referenced above addresses a back injury problem that is far from new, yet it still has no legal force. Standards for upper extremity cumulative trauma disorder prevention have lagged disease incidence by many years. Perhaps because of busy legislative agendas, we cannot expect rapid legal reaction, unless a highly visible major disaster occurs. Human factors problems are both chronic and acute, so that legislation based on acute problems as the sole basis for auditing is unlikely ever to be effective.

Despite the lack of legislation covering many human factors concerns, standards and other instantiations of good practice do have a place in ergonomics audits. Where they exist, they can be incorporated into an audit system without becoming the only criterion. Thus, noise levels in the United States have a legal limit for hearing protection purposes of 90 dBA. But at levels far below this, noise can disrupt communications (Jones and Broadbent 1987) and distract from task performance. An audit procedure can assess the noise on multiple criteria, that is, on hearing protection and on communication interruptions, with the former criterion used on all jobs and the latter only where verbal communication is an issue.

If standards and other good practices are used in a human factors audit, they provide a quantitative basis for decision making. Measurement reliability can be high and validity self-evident for legal standards. However, it is good practice in auditing to record only the measurement used, not its relationship to the standard, which can be established later. This removes any temptation by the analyst to bend the measurement to reach a predetermined conclusion. Illumination measurements, for example, can vary considerably over a workspace, so that an audit question:

Work Surface Illumination >750 Lux ☐ yes ☐ no

could be legitimately answered either way for some workspaces by choice of sampling point. Such temptation can be removed, for example, by an audit question.

Illumination at four points on workstation:

□ □ □ □ Lux

Later analysis can establish whether, for example, the mean exceeds 750 Lux or whether any of the four points fall below this level.

It is also possible to provide later analyses that combine the effects of several simple checklist responses, as in Parsons's (1992) thermal audit, where no single measure would exceed good practice even though the overall result would be cumulative heat stress.

2.3. Evaluation of an Audit System

For a methodology to be of value, it must demonstrate validity, reliability, sensitivity, and usability. Most texts that cover measurement theory treat these aspects in detail (e.g., Kerlinger 1964). Shorter treatments are found in human factors methodology texts (e.g., Drury 1990b; Osburn 1987).

Validity is the extent to which a methodology measures the phenomenon of interest. Does our ergonomics audit program indeed measure the quality of ergonomics in the plant? It is possible to measure validity in a number of ways, but ultimately all are open to argument. For example, if we do not know the true value of the quality of ergonomics in a plant, how can we validate our ergonomics audit program? Broadly, there are three ways in which validation can be tested.

Content validity is perhaps the simplest but least convincing measure. If each of the items of our measurement device displays the correct content, then validity is established. Theoretically, if we could list all of the possible measures of a phenomenon, content validity would describe how well our measurement device samples these possible measures. In practice it is assessed by having experts in the field judge each item for how well its content represents the phenomenon studied. Thus, the heat balance equation would be judged by most thermal physiologists to have a content that well represents the thermal load on an operator. Not all aspects are as easily validated!

Concurrent (or *prediction*) *validity* has the most immediate practical impact. It measures empirically how well the output of the measurement device correlates with the phenomenon of interest. Of course, we must have an independent measure of the phenomenon of interest, which raises difficulties. To continue our example, if we used the heat balance equation to assess the thermal load on operators, then there should be a high correlation between this and other measures of the effects of thermal load—perhaps measures such as frequency of temperature complaints or heat disorders: heat stroke, hyperthermia, hypothermia, and so on. In practice, however, measuring such correlations would be contaminated by, for example, propensity to report temperature problems or individual acclimatization to heat. Overall outputs from a human factors audit (if such overall outputs have any useful meaning) should correlate with other measures of ergonomic inadequacy, such as injuries, turnover, quality measures, or productivity. Alternatively, we can ask how well the audit findings agree with independent assessments of qualified human factors engineers (Keyserling et al. 1992; Koli et al. 1993) and thus validate against one interpretation of current good practice.

Finally, there is *construct validity,* which is concerned with inferences made from scores, evaluated by considering all empirical evidence and models. Thus, a model may predict that one of the variables being measured should have a particular relationship to another variable not in the measurement device. Confirming this relationship empirically would help validate the particular construct underlying our measured variable. Note that different parts of an overall measurement device can have their construct validity tested in different ways. Thus, in a board human factors audit, the thermal load could differentiate between groups of operators who do and do not suffer from thermal complaints. In the same audit, a measure of difficulty in a target aiming task could be validated against Fitts's law. Other ways to assess construct validity are those that analyze clusters or factors within a group of measures. Different workplaces audited on a variety of measures and the scores, which are then subjected to factor analysis, should show an interpretable, logical structure in the factors derived. This method has been used on large databases for job evaluation-oriented systems such as McCormick's position analysis questionnaire (PAQ) (McCormick 1979).

Reliability refers to how well a measurement device can repeat a measurement on the same sample unit. Classically, if a measurement X is assumed to be composed of a true value X_t and a random measurement error X_e, then

$$X = X_t + X_e$$

For uncorrelated X_t and X_e, taking variances gives:

$$\text{Variance}(X) = \text{variance}(X_t) + \text{variance}(X_e)$$

or

$$V(X) = V(X_t) + V(X_e)$$

We can define the reliability of the measurement as the fraction of measurement variance accounted for by true measurement variance:

$$\text{Reliability} = \frac{V(X_t)}{V(X_t) + V(X_e)}$$

Typically, reliability is measured by correlating the scores obtained through repeated measurements. In an audit instrument, this is often done by having two (or more) auditors use the instrument on the same set of workplaces. The square of the correlation coefficient between the scores (either overall scores, or separately for each logical construct) is then the reliability. Thus, PAQ was found to have an overall reliability of 0.79, tested using 62 jobs and two trained analysts (McCormick 1979).

Sensitivity defines how well a measurement device differentiates between different entities. Does an audit system for human–computer interaction find a difference between software generally acknowledged to be "good" and "bad"? If not, perhaps the audit system lacks sensitivity, although of course there may truly be no difference between the systems except what blind prejudice creates. Sensitivity can be adversely affected by poor reliability, which increases the variability in a measurement relative to a fixed difference between entities, that is, gives a poor signal-to-noise ratio. Low sensitivity can also come from a floor or ceiling effect. These arise where almost all of the measurements cluster at a high or low limit. For example, if an audit question on the visual environment was:

Does illumination exceed 10 lux? ☐ yes ☐ no

then almost all workplaces could answer "yes" (although the author has found a number that could not meet even this low criterion). Conversely, a floor effect would be a very high threshold for illluminance. Sensitivity can arise too when validity is in question. Thus, heart rate is a valid indicator of heat stress but not of cold stress. Hence, exposure to different degrees of cold stress would be only insensitively measured by heart rate.

Usability refers to the auditor's ease of use of the audit system. Good human factors principles should be followed, such as document design guidelines in constructing checklists (Patel et al. 1993; Wright and Barnard 1975). If the instrument does not have good usability, it will be used less often and may even show reduced reliability due to auditors' errors.

3. AUDIT SYSTEM DESIGN

As outlined in Section 2, the audit system must choose a sample, measure that sample, evaluate it, and communicate the results. In this section we approach these issues systematically.

An audit system is not just a checklist; it is a methodology that often includes the technique of a checklist. The distinction needs to be made between methodology and techniques. Over three decades ago, Easterby (1967) used Bainbridge and Beishon's (1964) definitions:

Methodology: a principle for defining the necessary procedures

Technique: a means to execute a procedural step.

Easterby notes that a technique may be applicable in more than one methodology.

3.1. The Sampling Scheme

In any sampling, we must define the unit of sampling, the sampling frame, and the sample choice technique. For a human factors audit the unit of sampling is not as self-evident as it appears. From a job-evaluation viewpoint (e.g., McCormick 1979), the natural unit is the job that is composed of a number of tasks. From a medical viewpoint the unit would be the individual. Human factors studies focus on the task/operator/machine/environment (TOME) system (Drury 1992) or equivalently the software/hardware/environment/liveware (SHEL) system (ICAO 1989). Thus, from a strictly human factors viewpoint, the specific combination of TOME can become the sampling unit for an audit program.

Unfortunately, this simple view does not cover all of the situations for which an audit program may be needed. While it works well for the rather repetitive tasks performed at a single workplace, typical of much manufacturing and service industry, it cannot suffice when these conditions do not hold. One relaxation is to remove the stipulation of a particular incumbent, allowing for jobs that require frequent rotation of tasks. This means that the results for one task will depend upon the incumbent chosen, or that several tasks will need to be combined if an individual operator is of interest. A second relaxation is that the same operator may move to different workplaces, thus changing environment as well as task. This is typical of maintenance activities, where a mechanic may perform any one of a repertoire of hundreds of tasks, rarely repeating the same task. Here the rational sampling unit is the task, which is observed for a particular operator at a particular machine in a particular environment. Examples of audits of repetitive tasks (Mir 1982; Drury 1990a) and maintenance tasks (Chervak and Drury 1995) are given below to illustrate these different approaches.

Definition of the sampling frame, once the sampling unit is settled, is more straightforward. Whether the frame covers a department, a plant, a division, or a whole company, enumeration of all sampling units is at least theoretically possible. All workplaces or jobs or individuals can in principle be listed, although in practice the list may never be up to date in an agile industry where change is the normal state of affairs. Individuals can be listed from personnel records, tasks from work orders or planning documents, and workplaces from plant layout plans. A greater challenge, perhaps, is to decide whether indeed the whole plant really is the focus of the audit. Do we include office jobs or just production? What about managers, chargehands, part-time janitors, and so on? A good human factors program would see all of these tasks or people as worthy of study, but in practice they may have had different levels of ergonomic effort expended upon them. Should some tasks or groups be excluded from the audit merely because most participants agree that they have few pressing human factors problems? These are issues that need to be decided explicitly before the audit sampling begins.

Choice of the sample from the sampling frame is well covered in sociology texts. Within human factors it typically arises in the context of survey design (Sinclair 1990). To make statistical inferences from the sample to the population (specifically to the sampling frame), our sampling procedure must allow the laws of probability to be applied. The most often-used sampling methods are:

Random sampling: Each unit within the sampling frame is equally likely to be chosen for the sample. This is the simplest and most robust method, but it may not be the most efficient. Where subgroups of interest (strata) exist and these subgroups are not equally represented in the sampling frame, one collects unnecessary information on the most populous subgroups and insufficient information on the least populous. This is because our ability to estimate a population statistic from a sample depends upon the absolute sample size and not, in most practical cases, on the population size. As a corollary, if subgroups are of no interest, then random sampling loses nothing in efficiency.

Stratified random sampling: Each unit within a particular stratum of the sampling frame is equally likely to be chosen for the sample. With stratified random sampling we can make valid inferences about each of the strata. By weighting the statistics to reflect the size of the strata within the sampling frame, we can also obtain population inferences. This is often the preferred auditing sampling method as, for example, we would wish to distinguish between different classes of tasks in our audits: production, warehouse, office, management, maintenance, security, and so on. In this way our audit interpretation could give more useful information concerning where ergonomics is being used appropriately.

Cluster sampling: Clusters of units within the sampling frame are selected, followed by random or nonrandom selection within clusters. Examples of clusters would be the selection of particular production lines within a plant (Drury 1990a) or selection of representative plants within a company or division. The difference between cluster and stratified sampling is that in cluster sampling only a subset of possible units within the sampling frame is selected, whereas in stratified sampling all of the sampling frame is used because each unit must belong to one stratum. Because clusters are not randomly selected, the overall sample results will not reflect population values, so that statistical inference is not possible. If units are chosen randomly within each cluster, then statistical inference within each cluster is possible. For example, if three production lines are chosen as clusters, and workplaces sampled randomly within each, the clusters can be regarded as fixed levels of a factor and the data subjected to analysis of variance to determine whether there are significant differences between levels of that factor. What is sacrificed in cluster sampling is the ability to make *population* statements. Continuing this example, we could state that the lighting in line A is better than in lines B or C but still not be able to make statistically valid statements about the plant as a whole.

3.2. The Data-Collection Instrument

So far we have assumed that the instrument used to collect the data from the sample is based upon measured data where appropriate. While this is true of many audit instruments, this is not the only way to collect audit data. Interviews with participants (Drury 1990a), interviews and group meetings to locate potential errors (Fox 1992), and archival data such as injury of quality records (Mir 1982) have been used. All have potential uses with, as remarked earlier, a judicious range of methods often providing the appropriate composite audit system.

One consideration on audit technique design and use is the extent of computer involvement. Computers are now inexpensive, portable, and powerful and can thus be used to assist data collection, data verification, data reduction, and data analysis (Drury 1990a). With the advent of more intelligent interfaces, checklist questions can be answered from mouse-clicks on buttons or selection from menus, as well as the more usual keyboard entry. Data verification can take place at entry time by checking for out-of-limits data or odd data such as the ratio of luminance to illuminance, implying a reflectivity greater than 100%. In addition, branching in checklists can be made easier, with only valid follow-on questions highlighted. The checklist user's manual can be built into the checklist software using context-sensitive help facilities, as in the EEAM checklist (Chervak and Drury 1995). Computers can, of course, be used for data reduction (e.g., finding the insulation value of clothing from a clothing inventory), data analysis, and results presentation.

With the case for computer use made, some cautions are in order. Computers are still bulkier than simple pencil-and-paper checklists. Computer reliability is not perfect, so inadvertent data loss is still a real possibility. Finally, software and hardware date much more rapidly than hard copy, so results safely stored on the latest media may be unreadable 10 years later. How many of us can still read punched cards or eight-inch floppy disks? In contrast, hard-copy records are still available from before the start of the computer era.

3.2.1. Checklists and Surveys

For many practitioners the proof of the effectiveness of an ergonomics effort lies in the ergonomic quality of the TOME systems it produces. A plant or office with appropriate human–machine function allocation, well-designed workplaces, comfortable environment, adequate placement/training, and inherently satisfying jobs almost by definition has been well served by human factors. Such a facility may not have human factors specialists, just good designers of environment, training, organization, and so on working independently, but this would generally be a rare occurrence. Thus, a checklist to measure such inherently ergonomic qualities has great appeal as part of an audit system.

Such checklists are almost as old as the discipline. Burger and deJong (1964) list four earlier checklists for ergonomic job analysis before going on to develop their own, which was commissioned by the International Ergonomics Association in 1961 and is usually known as the IEA checklist. It was based in part on one developed at the Philips Health Centre by G. J. Fortuin and provided in detail in Burger and deJong's paper.

Checklists have their limitations, though. The cogent arguments put forward by Easterby (1967) provide a good early summary of these limitations, and most are still valid today. Checklists are only of use as an aid to designers of systems at the earliest stages of the process. By concentrating on simple questions, often requiring yes/no answers, some checklists may reduce human factors to a simple stimulus–response system rather than encouraging conceptual thinking. Easterby quotes Miller (1967): "I still find that many people who should know better seem to expect magic from analytic and descriptive procedures. They expect that formats can be filled in by dunces and lead to inspired insights. . . . We should find opportunity to exorcise this nonsense" (Easterby 1967, p. 554)

Easterby finds that checklists can have a helpful structure but often have vague questions, make nonspecified assumptions, and lack quantitative detail. Checklists are seen as appropriate for some parts of ergonomics analysis (as opposed to synthesis) and even more appropriate to aid operators (not ergonomists) in following procedural steps. This latter use has been well covered by Degani and Wiener (1990) and will not be further presented here.

Clearly, we should be careful, even 30 years on, to heed these warnings. Many checklists are developed, and many of these published, that contain design elements fully justifying such criticisms.

A checklist, like any other questionnaire, needs to have both a helpful overall structure and well-constructed questions. It should also be proven reliable, valid, sensitive, and usable, although precious few meet all of these criteria. In the remainder of this section, a selection of checklists will be presented as typical of (reasonably) good practice. Emphasis will be on objective, structure, and question design.

3.2.1.1. The IEA Checklist The IEA checklist (Burger and de Jong 1964) was designed for ergonomic job analysis over a wide range of jobs. It uses the concept of functional load to give a logical framework relating the physical load, perceptual load, and mental load to the worker, the environment, and the working methods/tools/machines. Within each cell (or subcell, e.g., physical load could be static or dynamic), the load was assessed on different criteria such as force, time, distance, occupational, medical, and psychological criteria. Table 1 shows the structure and typical questions. Dirken (1969) modified the IEA checklist to improve the questions and methods of recording. He found that it could be applied in a median time of 60 minutes per workstation. No data are given on evaluation of the IEA checklist, but its structure has been so influential that it included here for more than historical interest.

3.2.1.2. Position Analysis Questionnaire The PAQ is a structured job analysis questionnaire using worker-oriented elements (187 of them) to characterize the human behaviors involved in jobs (McCormick et al. 1969). The PAQ is structured into six divisions, with the first three representing the classic experimental psychology approach (information input, mental process, work output) and

TABLE 1 IEA Checklist: Structure and Typical Questions

A: Structure of the Checklist		A	B	C
Load 1. Mean 2. Peaks Intensity, Frequency, Duration		Worker	Environment	Working method, tools, machines
I. Physical load	1. Dynamic 2. Static			
II. Perceptual load	1. Perception 2. Selection, decision 3. Control of movement			
III. Mental load	1. Individual 2. Group			
B: Typical Question				
I B. Physical load/environment		2.1. Physiological Criteria		
		1. Climate: high and low temperatures 1. Are these extreme enough to affect comfort or efficiency? 2. If so, is there any remedy? 3. To what extent is working capacity adversely affected? 4. Do personnel have to be specially selected for work in this particular environment?		

the other three a broader sociotechnical view (relationships with other persons, job context, other job characteristics). Table 2 shows these major divisions, examples of job elements in each and the rating scales employed for response (McCormick 1979).

Construct validity was tested by factor analyses of databases containing 3700 and 2200 jobs, which established 45 factors. Thirty-two of these fit neatly into the original six-division framework, with the remaining 13 being classified as "overall dimensions." Further proof of construct validity was based on 76 human attributes derived from the PAQ, rated by industrial psychologists and the ratings subjected to principal components analysis to develop dimensions "which had reasonably similar attribute profiles" (McCormick 1979, p. 204). Interreliability, as noted above, was 0.79, based on another sample of 62 jobs.

The PAQ covers many of the elements of concern to human factors engineers and has indeed much influenced subsequent instruments such as AET. With good reliability and useful (though perhaps dated), construct validity, it is still a viable instrument if the natural unit of sampling is the job. The exclusive reliance on rating scales applied by the analyst goes rather against current practice of comparison of measurements against standards or good practices.

3.2.1.3. AET (*Arbeit the Arbeitswissenschaftliche Erhebungsverfahren zur Tätikgkeitsanalyse*) The AET, published in German (Landau and Rohmert 1981) and later in English (Rohmert and Landau 1983), is the job-analysis subsystem of a comprehensive system of work studies. It covers "the analysis of individual components of man-at-work systems as well as the description and scaling of their interdependencies" (Rohmert and Landau 1983, pp. 9–10). Like all good techniques, it starts from a model of the system (REFA 1971, referenced in Wagner 1989), to which is added Rohmert's stress/strain concept. This latter sees strain as being caused by the intensity and duration of stresses impinging upon the operator's individual characteristics. It is seen as useful in the analysis of requirements and work design, organization in industry, personnel management, and vocational counseling and research.

AET itself was developed over many years, using PAQ as an initial starting point. Table 3 shows the structure of the survey instrument with typical questions and rating scales. Note the similarity between AET's job demands analysis and the first three categories of the PAQ and the scales used in AET and PAQ (Table 2).

Measurements of validity and reliability of AET are discussed by H. Luczak in an appendix to Landau and Rohment, although no numerical values are given. Cluster analysis of 99 AET records produced groupings which supported the AET constructs. Seeber et al. (1989) used AET along with

TABLE 2. PAQ: Structure and Typical Questions

A: Structure of the Checklist

Division	Definition	Examples of Questions
1. Information input	Where and how does the worker get the information he uses in performing his job?	1. Use of written materials 2. Near-visual differentiation
2. Mental processes	What reasoning, decision making, planning, and information processing activities are involved in performing the job?	1. Level of reasoning in problem solving 2. Coding/decoding
3. Work output	What physical activities does the worker perform and what tools or devices does he use?	1. Use of keyboard devices 2. Assembling/unassembling
4. Relationships with other persons	What relationships with other people are required in performing the job?	1. Instructing 2. Contacts with public or customers
5. Job context	In what physical or social contexts is the work performed?	1. High temperature 2. Interpersonal; conflict situations
6. Other job characteristics	What activities, conditions, or characteristics other than those described above are relevant to the job?	1. Specified work pace 2. Amount of job structure

B: Scales used to rate elements

Types of scale		Scale values	
Identification	Type of Rating	Rating	Definition
U	Extend to Use	N	Does not apply
I	Importance of the job	1	Very minor
T	Amount of Time	2	Low
P	Possibility of Occurrence	3	Average
A	Applicability (yes/no only)	4	High
S	Special code	5	Extreme

two other work-analysis methods on 170 workplaces. They found that AET provided the most differentiating aspects (suggesting sensitivity). They also measured postural complaints and showed that only the AET groupings for 152 female workers found significant differences between complaint levels, thus helping establish construct validity.

AET, like PAQ before it, has been used on many thousands of jobs, mainly in Europe. A sizable database is maintained that can be used for both norming of new jobs analyzed and analysis to test research hypotheses. It remain a most useful instrument for work analysis.

3.2.1.4. Ergonomics Audit Program (*Mir 1982; Drury 1990a*) This program was developed at the request of a multinational corporation to be able to audit its various divisions and plants as ergonomics programs were being instituted. The system developed was a methodology of which the workplace survey was one technique. Overall, the methodology used archival data or outcome measures (injury reports, personnel records, productivity) and critical incidents to rank order departments within a plant. A cluster sampling of these departments gives either the ones with highest need (if the aim is to focus ergonomic effort) or a sample representative of the plant (if the objective is an audit). The workplace survey is then performed on the sampled departments.

The workplace survey was designed based on ergonomic aspects derived from a task/operator/machine/environment model of the person at work. Each aspect formed a section of the audit, and sections could be omitted if there were clearly not relevant, for example, manual materials-handling aspects for data-entry clerks. Questions within each section were based on standards, guidelines, and models, such as the NIOSH (1981) lifting equation, *ASHRAE Handbook of Fundamentals* for thermal aspects, and Givoni and Goldman's (1972) model for predicting heart rate. Table 4 shows the major sections and typical questions.

TABLE 3 AET: Structure and Typical Questions

A: Structure of the Checklist

Part	Major Division	Section
A: Work systems analysis	1. Work objects	1.1. Material work objects 1.2 Energy as work object 1.3 Information as work object 1.4 Man, animals, plants as work objects
	2. Equipment	2.1 Working equipment 2.2 Other equipment
	3. Work environment	3.1 Physical environment 3.2 Organizational and social environment 3.3 Principles and methods of remuneration
B: Task analysis	1. Tasks relating to material work objects 2. Tasks relating to abstract work objects 3. Man-related tasks 4. Number and repetitiveness of tasks	
C: Job demand analysis	1. Demands on perception	1.1 Mode of perception 1.2 Absolute/relative evaluation of perceived information 1.3 Accuracy of perception
	2. Demands for decision	2.1 Complexity of decisions 2.2 Pressure of time 2.3 Required knowledge
	3. Demands for response/activity	3.1 Body postures 3.2 Static work 3.3 Heavy muscular work 3.4 Light muscular work, active light work 3.5 Strenuousness and frequency of moves

B: Types of scale		Typical Scale values	
Code	Type of Rating	Duration Value	Definition
A	Does this apply?	0	Very infrequent
F	Frequency	1	Less than 10% of shift time
S	Significance	2	Less than 30% of shift time
D	Duration	3	30% to 60% of shift time
		4	More than 60% of shift time
		5	Almost continuously during whole shift

Data were entered into the computer program and a rule-based logic evaluated each section to provide messages to the user in the form of either a "section shows no ergonomic problems" message:

```
MESSAGE
Results from analysis of auditory aspects:
       Everything OK in this section
```

or discrepancies from a single input:

```
MESSAGE
Seats should be padded, covered with non-slip materials and have front
edge rounded
```

or discrepancies based on the integration of several inputs:

TABLE 4 Workplace Survey: Structure and Typical Questions

Section	Major Classification	Examples of Questions
1. Visual aspects		Nature of task Measure illuminance at task midfield outer field
2. Auditory aspects		Noise level, dBA Main source of noise
3. Thermal aspects		Strong radiant sources present? Wet bulb temperature (Clothing inventory)
4. Instruments, controls, displays	Standing vs. Seated Displays Labeling Coding Scales, dials, counters Control/display relationships Controls	Are controls mounted between 30 in. and 70 in. Signals for crucial visual checks Are trade names deleted? Color codes same for control & display? All numbers upright on fixed scales? Grouping by sequence or subsystem? Emergency button diameter > 0.75 in.?
5. Design of workplaces	Desks Chairs Posture	Seat to underside of desk > 6.7 in.? Height easily adjustable 15–21 in.? Upper arms vertical?
6. Manual materials handling	(NIOSH Lifting Guide, 1981)	Task, H, V, D, F
7. Energy expenditure		Cycle time Object weight Type of work
8. Assembly/repetitive aspects		Seated, standing, or both? If heavy work, is bench 6–16 in. below elbow height?
9. Inspection aspects		Number of fault types? Training time until unsupervised?

```
MESSAGE
The total metabolic workload is 174 watts
Intrinsic clothing insulation is 0.56 clo
Initial rectal temperature is predicted to be 36.0°C
Final rectal temperature is predicted to be 37.1°C
```

Counts of discrepancies were used to evaluate departments by ergonomics aspect, while the messages were used to alert company personnel to potential design changes. This latter use of the output as a training device for nonergonomic personnel was seen as desirable in a multinational company rapidly expanding its ergonomics program.

Reliability and validity have not been assessed, although the checklist has been used in a number of industries (Drury 1990a). The Workplace Survey has been included here because, despite its lack of measured reliability and validity, it shows the relationship between audit as methodology and checklist as technique.

3.2.1.5. ERGO, EEAM, and ERNAP (*Koli et al. 1993; Chervak and Drury 1995*) These checklists are both part of complete audit systems for different aspects of civil aircraft hangar activities. They were developed for the Federal Aviation Administration to provide tools for assessing human factors in aircraft inspection (ERGO) and maintenance (EEAM) activities, respectively. Inspection and maintenance activities are nonrepetitive in nature, controlled by task cards issued to technicians at the start of each shift. Thus, the sampling unit is the task card, not the workplace, which is highly variable between task cards. Their structure was based on extensive task analyses of inspection and maintenance tasks, which led to generic function descriptions of both types of work (Drury et al. 1990). Both systems have sampling schemes and checklists. Both are computer based with initial data collection on either hard copy or direct into a portable computer. Recently, both have been combined into a single program (ERNAP) distributed by the FAA's Office of Aviation Medicine. The structure of ERNAP and typical questions are given in Table 5.

TABLE 5 ERNAP Structure and Typical Questions

Audit Phase	Major Classification	Examples of Questions
I. Premaintenance	Documentation	Is feedforward information on faults given?
	Communication	Is shift change documented?
	Visual characteristics	If fluorescent bulbs are used, does flicker exist?
	Electric/pneumatic equipment	Do push buttons prevent slipping of fingers?
	Access equipment	Do ladders have nonskid surfaces on landings?
II. Maintenance	Documentation (M)	Does inspector sign off workcard after each task?
	Communication (M)	Explicit verbal instructions from supervisor?
	Task lighting	Light levels in four zones during task, fc.
	Thermal issues	Wet bulb temperature in hanger bay, °C
	Operator perception	Satisfied with summer thermal environment?
	Auditory issues	Noise levels at five times during task, dBA
	Electrical and pneumatic	Are controls easily differentiated by touch?
	Access equipment (M)	Is correct access equipment available?
	Hand tools	Does the tool handle end in the palm?
	Force measurements	What force is being applied, kg?
	Manual Materials handling	Does task require pushing or pulling forces?
	Vibration	What is total duration of exposure on this shift?
	Repetitive motion	Does the task require flexion of the wrist?
	Access	How often was access equipment repositioned?
	Posture	How often were following postures adopted?
	Safety	Is inspection area adequately cleaned for inspect?
	Hazardous material	Were hazardous materials signed out and in?
III. Postmaintenance	Buy back	Are discrepancy worksheets readable?

As in Mir's Ergonomics Audit Program, the ERNAP, the checklist is again modular, and the software allows formation of data files, selection of required modules, analysis after data entry is completed, and printing of audit reports. Similarly, the ERGO, EEAM, and ERNAP instruments use quantitative or Yes/No questions comparing the entered value with standards and good practice guides. Each takes about 30 minutes per task. Output is in the form of an audit report for each workplace, similar to the messages given by Mir's Workplace Survey, but in narrative form. Output in this form was chosen for compatibility with existing performance and compliance audits used by the aviation maintenance community.

Reliability of a first version of ERGO was measured by comparing the output of two auditors on three tasks. Significant differences were found at $P < 0.05$ on all three tasks, showing a lack of interrater reliability. Analysis of these differences showed them to be largely due to errors on questions requiring auditor judgment. When such questions were replaced with more quantitative questions, the two auditors had no significant disagreements on a later test. Validity was measured using concurrent validation against six Ph.D. human factors engineers who were asked to list all ergonomic issues on a power plant inspection task. The checklist found more ergonomic issues than the human factors engineers. Only a small number of issues were raised by the engineers that were missed by the checklist. For the EEAM checklist, again an initial version was tested for reliability with two auditors, and it only achieved the same outcome for 85% of the questions. A modified version was tested and the reliability was considered satisfactory with 93% agreement. Validity was again tested against four human factors engineers, this time the checklist found significantly more ergonomic issues than the engineers without missing any issues they raised.

The ERNAP audits have been included here to provide examples of a checklist embedded in an audit system where the workplace is *not* the sampling unit. They show that non-repetitive tasks can be audited in a valid and reliable manner. In addition, they demonstrate how domain-specific audits can be designed to take advantage of human factors analyses already made in the domain.

3.2.1.6. Upper-Extremity Checklist (*Keyserling et al. 1993*) As its name suggests, this checklist is narrowly focused on biomechanical stresses to the upper extremities that could lead to cumulative trauma disorders (CTDs). It does not claim to be a full-spectrum analysis tool, but it is included here as a good example of a special-purpose checklist that has been carefully constructed and validated. The checklist (Table 6) was designed for use by management and labor to fulfill a requirement in the OSHA guidelines for meat-packing plants. The aim is to screen jobs rapidly for harmful exposures rather than to provide a diagnostic tool. Questions were designed based upon the biomechanical literature, structured into six sections. Scoring was based on simple presence or absence of a condition, or on a three-level duration score. As shown in Table 6, the two or three levels were scored as o, ·, or * depending upon the stress rating built into the questionnaire. These symbols represented insignificant, moderate, or substantial exposures. A total score could be obtained by summing moderate and substantial exposures.

The upper extremity checklist was designed to be biased towards false positives, that is, to be very sensitive. It was validated against detailed analyses of 51 jobs by an ergonomics expert. Each section (except the first, which only recorded dominant hand) was considered as giving a positive screening if at least one * rating was recorded. Across the various sections, there was reasonable agreement between checklist users and the expert analysis, with the checklist, being generally more sensitive, as was its aim. The original reference shows the findings of the checklist when applied to 335 manufacturing and warehouse jobs.

As a special-purpose technique in an area of high current visibility for human factors, the upper extremity checklist has proven validity, can be used by those with minimal ergonomics training for screening jobs, and takes only a few minutes per workstation. The same team has also developed

TABLE 6 Upper Extremity Checklist: Structure, Questions, and Scoring

A: Structure of the Checklist

Major Section	Examples of Questions
Worker information	Which hand is dominant?
Repetitiveness	Repetitive use of the hands and wrists? If "yes" then: Is cycle < 30 sec? Repeated for > 50% cycle?
Mechanical stress	Do hard or sharp objects put pressure localized pressure on: back or side of fingers? Palm or base of hand . . .
Force	Lift, carry, push or pull objects > 4.5 kg? If gloves worn, do they hinder gripping? . . .
Posture	Is pinch grip used? Is there wrist deviation? . . .
Tools, hand-held objects and equipment	Is vibration transmitted to the operator's hand? Does cold exhaust air blow on the hand or wrist? . . .

B. Scoring scheme

Question	Scoring		
Is there wrist deviation?	No o	Some √	> 33% cycle *

C. Overall evaluation

Total Score	Number of √ + Number of *

and validated a legs, trunk, and neck job screening procedure along similar lines (Keyserling et al. 1992).

3.2.1.7. Ergonomic Checkpoints The Workplace Improvement in Small Enterprises (WISE) methodology (Kogi 1994) was developed by the International Ergonomics Association (IEA) and the International Labour Office (ILO) to provide cost-effective solutions for smaller organizations. It consists of a training program and a checklist of potential low-cost improvements. This checklist, called ergonomics checkpoints, can be used both as an aid to discovery of solutions and as an audit tool for workplaces within an enterprise.

The 128-point checklist has now been published (Kogi and Kuorinka 1995). It covers the nine areas shown in Table 7. Each item is a statement rather than a question and is called a checkpoint. For each checkpoint there are four sections, also shown in Table 7. There is no scoring system as such; rather, each checkpoint becomes a point of evaluation of each workplace for which it is appropriate. Note that each checkpoint also covers why that improvement is important, and a description of the core issues underlying it. Both of these help the move from rule-based reasoning to knowledge-based reasoning as nonergonomists continue to use the checklist. A similar idea was embodied in the Mir (1982) ergonomic checklist.

3.2.1.8. Other Checklists The above sample of successful audit checklists has been presented in some detail to provide the reader with their philosophy, structure, and sample questions. Rather then continue in the same vein, other interesting checklists are outlined in Table 8. Each entry shows the domain, the types of issues addressed, the size or time taken in use, and whether validity and reliability have been measured. Most textbooks now provide checklists, and a few of these are cited. No claim is made that Table 8 is comprehensive. Rather, it is rather a sampling with references so that readers can find a suitable match to their needs. The first nine entries in the table are conveniently colocated in Landau and Rohmert (1989). Many of their reliability and validity studies are reported in this publication. The next entries are results of the Commission of European Communities fifth ECSC program, reported in Berchem-Simon (1993). Others are from texts and original references. The author has not personally used all of these checklists and thus cannot specifically endorse them. Also, omission of a checklist from this table implies nothing about its usefulness.

TABLE 7 Ergonomic Checkpoints: Structure, Typical Checkpoints, and Checkpoint Structure

A: Structure of the Checklist

Major Section	Typical Checkpoints
Materials handling	• Clear and mark transport ways.
Handtools	• Provide handholds, grips, or good holding points for all packages and containers.
Productive machine safety	• Use jigs and fixtures to make machine operations stable, safe, and efficient.
Improving workstation design	• Adjust working height for each worker at elbow level or slightly below it.
Lighting	• Provide local lights for precision or inspection work.
Premises	• Ensure safe wiring connections for equipment and lights.
Control of hazards	• Use feeding and ejection devices to keep the hands away from dangerous parts of machinery.
Welfare facilities	• Provide and maintain good changing, washing, and sanitary facilities to keep good hygiene and tidiness.
Work organization	• Inform workers frequently about the results of their work.

B. Structure of each checkpoint

WHY?	Reasons why improvments are important.
HOW?	Description of several actions each of which can contribute to improvement.
SOME MORE HINTS	Additional points which are useful for attaining the improvement.
POINTS TO REMEMBER	Brief description of the core element of the checkpoint.

From Kogi, private communication, November 13, 1995.

TABLE 8 A Selection of Published Checklists

Name	Authors	Coverage	Reliability	Validity
TBS	Hacker et al. 1983	Mainly mental work		vs. AET
VERA	Volpert et al. 1983	Mainly mental work		vs. AET
RNUR	RNUR, 1976	Mainly physical work		
LEST	Guèlaud. 1975	Mainly physical work		
AVISEM	AVISEM. 1977	Mainly physical work		
GESIM	GESIM. 1988	Mainly physical work		
RHIA	Leitner et al. 1987	Task hindrances, stress	0.53–0.79	vs. many
MAS	Groth. 1989	Open structure, derived from AET		vs. AET
JL and HA	Mattila and Kivi. 1989	Mental, physical work, hazards	0.87–0.95	
	Bolijn 1993	Physical work checklist for women	tested	
	Panter 1993	Checklist for load handling		
	Portillo Sosa 1993	Checklist for VDT standards		
Work Analy.	Pulat 1992	Mental and physical work		
Thermal Aud.	Parsons 1992	Thermal audit from heat balance		content
WAS	Yoshida and Ogawa, 1991	Workplace and environment	tested	vs. expert
Ergonomics	Occupational Health and Safety Authority 1990	Short workplace checklists		
	Cakir et al. 1980	VDT checklist		

First nine from Landau and Rohmert 1989; next three from Berchem-Simon 1993.

3.2.2. Other Data-Collection Methods

Not all data come from checklists and questionnaires. We can audit a human factors program using outcome measures alone (e.g., Chapter 47). However, outcome measures such as injuries, quality, and productivity are nonspecific to human factors: many other external variables can affect them. An obvious example is changes in the reporting threshold for injuries, which can lead to sudden apparent increases and decreases in the safety of a department or plant. Additionally, injuries are (or should be) extremely rare events. Thus, to obtain enough data to perform meaningful statistical analysis may require aggregation over many disparate locations and/or time periods. In ergonomics audits, such outcome measures are perhaps best left for long-term validation or for use in selecting cluster samples.

Besides outcome measures, interviews represent a possible data-collection method. Whether directed or not (e.g., Sinclair 1990) they can produce critical incidents, human factors examples, or networks of communication (e.g., Drury 1990a), which have value as part of an audit procedure. Interviews are routinely used as part of design audit procedures in large-scale operations such as nuclear power plants (Kirwan 1989) or naval systems (Malone et al. 1988).

A novel interview-based audit system was proposed by Fox (1992) based on methods developed in British Coal (reported in Simpson 1994). Here an error-based approach was taken, using interviews and archival records to obtain a sampling of actual and possible errors. These were then classified using Reason's (1990) active/latent failure scheme and orthogonally by Rasmussen's (1987) skill-, rule-, knowledge-based framework. Each active error is thus a conjunction of skill/mistake/violation with skill/rule/knowledge. Within each conjunction, performance-shaping factors can be deduced and sources of management intervention listed. This methodology has been used in a number of mining-related studies: examples will be presented in Section 4.

3.3. Data Analysis and Presentation

Human factors as a discipline covers wide range of topics, from workbench height to function allocation in automated systems. An audit program can only hope to abstract and present a part of this range. With our consideration of sampling systems and data collection devices we have seen different ways in which an unbiased abstraction can be aided. At this stage the data consist of large numbers of responses to large numbers of checklist items, or detailed interview findings. How can, or should, these data be treated for best interpretation?

Here there are two opposing viewpoints: one is that the data are best summarized across sample units, but not across topics. This is typically the way the human factors professional community treats the data, giving summaries in published papers of the distribution of responses to individual items on the checklist. In this way, findings can be more explicit, for example that the lighting is an area that needs ergonomics effort, or that the seating is generally poor. Adding together lighting and seating discrepancies is seen as perhaps obscuring the findings rather than assisting in their interpretation.

The opposite viewpoint, in many ways, is taken by the business community. For some, an overall figure of merit is a natural outcome of a human factors audit. With such a figure in hand, the relative needs of different divisions, plants, or departments can be assessed in terms of ergonomic and engineering effort required. Thus, resources can be distributed rationally from a management level. This view is heard from those who work for manufacturing and service industries, who ask after an audit "How did we do?" and expect a very brief answer. The proliferation of the spreadsheet, with its ability to sum and average rows and columns of data, has encouraged people to do just that with audit results. Repeated audits fit naturally into this view because they can become the basis for monthly, quarterly, or annual graphs of ergonomic performance.

Neither view alone is entirely defensible. Of course, summing lighting and seating needs produces a result that is logically indefensible and that does not help diagnosis. But equally, decisions must be made concerning optimum use of limited resources. The human factors auditor, having chosen an unbiased sampling scheme and collected data on (presumably) the correct issues, is perhaps in an excellent position to assist in such management decisions. But so too are other stakeholders, primarily the workforce.

Audits, however, are not the only use of some of the data-collection tools. For example, the Keyserling et al. (1993) upper extremity checklist was developed specifically as a screening tool. Its objective was to find which jobs/workplaces are in need of detailed ergonomic study. In such cases, summing across issues for a total score has an operational meaning, that is, that a particular workplace needs ergonomic help.

Where interpretation is made at a deeper level than just a single number, a variety of presentation devices have been used. These must show scores (percent of workplaces, distribution of sound pressure levels, etc.) separately but so as to highlight broader patterns. Much is now known about separate vs. integrated displays and emergent features (e.g., Wickens 1992, pp. 121–122), but the traditional profiles and spider web charts are still the most usual presentation forms. Thus, Wagner (1989) shows the AVISEM profile for a steel industry job before and after automation. The nine different issues (rating factors) are connected by lines to show emergent shapes for the old and the new jobs. Landau and Rohmert's (1981) original book on AET shows many other examples of profiles. Klimer et al. (1989) present a spider web diagram to show how three work structures influenced ten issues from the AET analysis. Mattila and Kivi (1989) present their data on the job load and hazard analysis system applied to the building industry in the form of a table. For six occupations, the rating on five different loads/hazards is presented as symbols of different sizes within the cells of the table.

There is little that is novel in the presentation of audit results: practitioners tend to use the standard tabular or graphical tools. But audit results are inherently multidimensional, so some thought is needed if the reader is to be helped towards an informed comprehension of the audit's outcome.

4. AUDIT SYSTEMS IN PRACTICE

Almost any of the audit programs and checklists referenced in previous sections give examples of their use in practice. Only two examples will be given here, as others are readily accessible. These examples were chosen because they represent quite different approaches to auditing.

4.1. Auditing a Decentralized Business

From 1992 to 1996, a major U.S.-based apparel manufacturer had run an ergonomics program aimed primarily at the reduction of workforce injuries in backs and upper extremities. As detailed in Drury et al. (1999), the company during that time was made up of nine divisions and employed about 45,000 workers. Of particular interest was the fact that the divisions enjoyed great autonomy, with only a small corporate headquarters with a single executive responsible for all risk-management activities. The company had grown through mergers and acquisitions, meaning that different divisions had different degrees of vertical integration. Hence, core functions such as sewing, pressing, and distribution were common to most divisions, while some also included weaving, dyeing, and embroidery. In addition, the products and fabrics presented quite different ergonomic challenges, from delicate undergarments to heavy jeans to knitted garments and even luggage.

The ergonomics program was similarly diverse. It started with a corporate launch by the highest-level executives and was rolled out to the divisions and then to individual plants. The pace of change was widely variable. All divisions were given a standard set of workplace analysis and modification tools (based on Drury and Wick 1984) but were encouraged to develop their own solutions to problems in a way appropriate to their specific needs.

Evaluation took place continuously, with regular meetings between representatives of plants and divisions to present results of before-and-after workplace studies. However, there was a need for a broader audit of the whole corporation aimed at understanding how much had been achieved for the multimillion-dollar investment, where the program was strong or weak, and what program needs were emerging for the future. A team of auditors visited all nine divisions, and a total of 12 plants spread across eight divisions, during 1995. This was three years after the initial corporate launch and about two years after the start of shop-floor implementation.

A three-part audit methodology was used. First, a workplace survey was developed based on elements of the program itself, supplemented by direct comparisons to ergonomics standards and good practices. Table 9 shows this 50-item survey form, with data added for the percentage of ''yes'' answers where the responses were not measures or scale values. The workplace survey was given at a total of 157 workplaces across the 12 plants. Second, a user survey (Table 10) was used in an interview format with 66 consumers of ergonomics, typically plant managers, production managers, human resource managers, or their equivalent at the division level, usually vice presidents. Finally, a total of 27 providers of ergonomics services were given a similar provider survey (Table 11) interview. Providers were mainly engineers, with three human resources specialists and one line supervisor. From these three audit methods the corporation wished to provide a time snapshot of how effectively the current ergonomics programs was meeting their needs for reduction of injury costs. While the workplace survey measured how well ergonomics was being implemented at the workplace, the user and provider surveys provided data on the roles of the decision makers beyond the workplace.

Detailed audit results are provided in Drury et al. (1999), so only examples and overall conclusions are covered in this chapter. Workplaces showed some evidence of good ergonomic practice, with generally satisfactory thermal, visual, and auditory environments. There were some significant differences ($p < 0.05$) between workplace types rather than between divisions or plants; for example, better lighting (> 700 lux) was associated with inspection and sewing. Also, higher thermal load was associated with laundries and machine load/unload. Overall, 83% of workplaces met the ASHRAE (1990) summer comfort zone criteria. As seen in Table 12, the main ergonomics problem areas were in poor posture and manual materials handling. Where operators were seated (only 33% of all workplaces) seating was relatively good. In fact, many in the workforce had been supplied with well-designed chairs as part of the ergonomics program.

To obtain a broad perspective, the three general factors at the end of Table 9 were analyzed. Apart from cycle time (W48), the questions related to workers having seen the corporate ergonomics video (W49) and having experienced a workplace or methods change (W50). Both should have received a ''yes'' response if the ergonomics program were reaching the whole workforce. In fact, both showed highly significant differences between plants ($X_8^2 = 92.0$, $p < 0.001$, and $X_8^2 = 22.2$, $p < 0.02$, respectively). Some of these differences were due to two divisions lagging in ergonomics implementation, but even beyond this were large between-plant differences. Overall, 62% of the workforce had seen the ergonomics video, a reasonable value but one with wide variance between plants and divisions. Also, 38% of workplaces had experienced some change, usually ergonomics-related, a respectable figure after only two to three years of the program.

From the user and provider surveys an enhanced picture emerged. Again, there was variability between divisions and plants, but 94% of the users defined ergonomics as fitting the job to the operator rather than training or medical management of injuries. Most users had requested an ergonomic intervention within the past two months, but other ''users'' had never in fact used ergonomics.

The solutions employed ranged widely, with a predominance of job aids such as chairs or standing pads. Other frequent categories were policy changes (e.g., rest breaks, rotation, box weight reduction) and workplace adjustment to the individual operator. There were few uses of personal aids (e.g. splints) or referrals to MDs as ergonomic solutions. Changes to the workplace clearly predominated over changes to the individual, although a strong medical management program was in place when required. When questioned about ergonomics results, all mentioned safety (or workplace comfort or ease of use), but some also mentioned others. Cost or productivity benefits were the next most common response, with a few additional ones relating to employee relations, absence/turnover, or job satisfaction. Significantly, only one respondent mentioned quality.

The major user concern at the plant level was time devoted to ergonomics by providers. At the corporate level, the need was seen for more rapid job-analysis methods and corporate policies, such as on back belts or ''good'' chairs. Overall, 94% of users made positive comments about the ergonomics program.

Ergonomics providers were almost always trained in the corporate or division training seminars, usually near the start of the program. Providers' chief concern was for the amount of time and resources they could spend on ergonomics activities. Typically, ergonomics was only one job responsibility among many. Hence, broad programs, such as new chairs or back belts, were supported enthusiastically because they gave the maximum perceived impact for the time devoted. Other solutions presented included job aids, workplace redesign (e.g., moving from seated to standing jobs for long-seam sewing), automation, rest breaks, job rotation, packaging changes, and medical man-

TABLE 9 Ergonomics Audit: Workplace Survey with Overall Data

Number			Division	Plant	Job Type
1. Postural aspects					
	Yes	No	Factor		
W1	68%		Frequent extreme motions of back, neck, shoulders, wrists		
W2	66%		Elbows raised or unsupported more than 50% of time		
W3	22%		Upper limbs contact nonrounded edges		
W4	73%		Gripping with fingers		
W5	36%		Knee/foot controls		
1.1 Seated					
	Yes	No	Factor		
W6	12%		Leg clearance restricted		
W7	21%		Feet unsupported/legs slope down		
W8	17%		Chair/table restricts thighs		
W9	22%		Back unsupported		
W10	37%		Chair height not adjustable easily		
1.2 Standing					
	Yes	No	Factor		
W11	3%		Control requires weight on one foot more than 50% time		
W12	37%		Standing surface hard		
W13	92%		Work surface height not adjustable easily		
1.3 Hand tools					
	Yes	No	Factor		
W14	77%		Tools require hand/wrist bending		
W15	9%		Tools vibrate		
W16	63%		Restricted to one-handed use		
W17	39%		Tool handle ends in palm		
W18	20%		Tool handle has nonrounded edges		
W19	56%		Tool uses only 2 or 3 fingers		
W20	9%		Requires continuous or high force		
W21	41%		Tool held continuously in one hand		
2. Vibration					
	Yes	No	Factor		
W22	14%		Vibration reaches body from any source		
3. Manual materials handling					
	Yes	No	Factor		
W23	40%		More than 5 moves per minute		
W24	36%		Loads unbalanced		
W25	14%		Lift above head		
W26	28%		Lift off floor		
W27	83%		Reach with arms		
W28	78%		Twisting		
W29	60%		Bending trunk		
W30	3%		Floor wet or slippery		
W31	0%		Floor in poor condition		
W32	17%		Area obstructs task		
W33	4%		Protective clothing unavailable		
W34	2%		Handles used		

TABLE 9 (*Continued*)

Number			Division	Plant	Job Type
4. Visual aspects					
	Yes	No	Factor		
W35			Task nature: 1 = rough, 2 = moderate, 3 = fine, 4 = very fine		
W36			Glare/reflection: 0 = none, 1 = noticeable, 2 = severe		
W37			Colour contrast: 0 = none, 1 = noticeable, 2 = severe		
W38			Luminance contrast: 0 = none, 1 = noticeable, 2 = severe		
W39			Task illuminance, foot candles		
W40	69%		Luminance: Task > Midfield > Outerfield = yes		
5. Thermal aspects					
			Factor		
W41			Dry bulb temperature, °F		
W42			Relative humidity, %		
W43			Air speed: 1 = just perceptible, 2 = noticeable, 3 = severe		
W44			Metabolic cost		
W45			Clothing, clo value		
6. Auditory aspects					
			Factor		
W46			Maximum sound pressure level, dBA		
W47			Noise sources 1 = m/c, 2 = other m/c, 3 = general, 4 = other		
7. General factors					
	Yes	No	Factor		
W48			Primary cycle time, sec		
W49	62%		Seen ergonomics video		
W50	38%		Any ergonomics changes to workplace or methods		

agement. Specific needs were seen in the area of corporate or supplier help in obtaining standard equipment solutions and of more division-specific training. As with users, the practitioners enjoyed their ergonomics activity and thought it worthwhile.

Recommendations arising from this audit were that the program was reasonably effective at that time but had some long-term needs. The corporation saw itself as an industry leader and wanted to move beyond a relatively superficial level of ergonomics application. To do this would require more time resources for job analysis and change implementation. Corporate help could also be provided in developing more rapid analysis methods, standardized video-based training programs, and more standardized solutions to recurring ergonomics problems. Many of these changes have since been implemented.

On another level, the audit was a useful reminder to the company of the fact that it had incurred most of the up-front costs of a corporate ergonomics program, and was now beginning to reap the benefits. Indeed, by 1996, corporate injury costs and rates had decreased by about 20% per year after

TABLE 10 Ergonomics Audit: User Survey

Number	Division	Plant	Job Type
U1. What is ergonomics?			
U2. Who do you call to do ergonomics?			
U3. When did you last ask them to do ergonomics?			
U4. Describe what they did?			
U5. Who else should we talk to about ergonomics?			
U6. General comments on ergonomics.			

TABLE 11 Ergonomics Audit: Provider Survey

Number	Division	Plant	Job Type

P1. What do you do?
P2. How do you get contacted to do ergonomics?
P3. When were you last asked to do ergonomics?
P4. Describe what you did.
P5. How long have you been doing ergonomics?
P6. How were you trained in ergonomics?
P7. What percent of your time is spent on ergonomics?
P8. Where do you go for more detailed ergonomics help?
P9. What ergonomics implementation problems have you had?
P10. How well are you regarded by management?
P11. How well are you regarded by workforce?
P12. General comments on ergonomics.

peaking in 1993. Clearly, the ergonomics program was not the only intervention during this period, but it was seen by management as the major contributor to improvement. Even on the narrow basis of cost savings, the ergonomics program was a success for the corporation.

4.2. Error Reduction at a Colliery

In a two-year project, reported by Simpson (1994) and Fox (1992), the human error audit described in Section 3.2 was applied to two colliery haulage systems. The results of the first study will be presented here. In both systems, data collection focused on potential errors and the performance-shaping factors (PSFs) that can influence these errors. Data was collected by ''observation, discussion and measurement within the framework of the broader man-machine systems and checklist of PSFs,'' taking some 30–40 shifts at each site. The whole haulage system from surface operations to delivery at the coal face was covered.

The first study found 40 active failures (i.e., direct error precursors) and nine latent failures (i.e., dormant states predisposing the system to later errors). Four broad classes of active failures were:

1. Errors associated with locomaintenance (7 errors), e.g., fitting incorrect thermal cut-offs
2. Errors associated with locooperation (10 errors), e.g., locos not returned to service bay for 24-hour check.
3. Errors associated with loads and load security (7 errors); e.g., failure to use spacer wagons between overhanging loads
4. Errors associated with the design/operation of the haulage route (10 errors), e.g., continued use despite potentially unsafe track
5. Plus a small miscellaneous category

The latent failures were (Fox 1992):

1. Quality assurance in supplying companies
2. Supplies ordering procedures within the colliery
3. Locomotive design
4. Surface make-up of supplies
5. Lack of equipment at specific points
6. Training
7. Attitudes to safety
8. The safety inspection/reporting/action procedures

As an example from 3, Locomotive design, the control positions were not consistent across the locomotives fleet, despite all originating from the same manufacturer.

Using the slip/mistake/violation categorization, each potential error could be classified so that the preferred source of action (intervention) could be specified.

This audit led to the formation of two teams, one to tackle locomotive design issues and the other for safety reporting and action. As a result of team activities, many ergonomic actions were implemented. These included management actions to ensure a uniform wagon fleet, autonomous inspection/repair teams for tracks, and multifunctional teams for safety initiatives.

TABLE 12 Responses to Ergonomics User

Question and Issue	Corporate Mgt	Corporate Staff	Plant Mgt	Plant Staff
1. What is Ergonomics?				
1.1 Fitting job to operator	1	6	10	5
1.2 Fitting operator to job	0	6	0	0
2. Who do you call on to get ergonomics work done?				
2.1 Plant ergonomics people	0	3	3	2
2.2 Division ergonomics people	0	4	5	2
2.3 Personnel department	3	0	0	0
2.4 Engineering department	1	8	6	11
2.5 We do it ourselves	0	2	1	0
2.6 College interns	0	0	4	2
2.7 Vendors	0	0	0	1
2.8 Everyone	0	1	0	0
2.9 Operators	0	1	0	0
2.10 University faculty	0	0	1	0
2.11 Safety	0	1	0	0
3. When did you last ask them for help?				
3.1 Never	0	4	2	0
3.2 Sometimes/infrequently	2	0	1	0
3.3 One year or more ago	0	1	4	0
3.4 One month or so ago	0	0	2	0
3.5 less than 1 month ago	1	0	3	4
5. Who else should we talk to about ergonomics?				
5.1 Engineers	0	0	3	2
5.2 Operators	1	1	2	0
5.3 Everyone	0	0	2	0
6. General Ergonomics Comments				
6.1 Ergonomics Concerns				
6.11 Workplace design for safety/ease/stress/fatigue	2	5	13	5
6.12 Workplace design for cost savings/productivity	1	0	2	1
6.13 Workplace design for worker satisfaction	1	1	0	1
6.14 Environment design	2	1	3	0
6.15 The problem of finishing early	0	0	1	1
6.16 The Seniority/bumping problem	0	3	1	0
6.2 Ergonomics program concerns				
6.21 Level of reporting of ergonomics	0	1	7	0
6.22 Communication/who does erognomics	7	1	4	0
6.23 Stability/staffing of ergonomics	0	0	10	4
6.24 General evaluation of ergonomics				
Positive	1	3	3	4
Negative	4	10	10	3
6.25 Lack of financial support for ergonomics	0	0	1	0
6.26 Lack of priority for ergonomics	2	2	1	4
6.27 Lack of awareness of ergonomics	2	1	6	1

The outcome was that the accident rate dropped from 35.40 per 100,000 person-shifts to 8.03 in one year. This brought the colliery from worst in the regional group of 15 collieries to best in the group, and indeed in the United Kingdom. In addition, personnel indicators, such as industrial relations climate and absence rates, improved.

5. FINAL THOUGHTS ON HUMAN FACTORS AUDITS

An audit system is a specialized methodology for evaluating the ergonomic status of an organization at a point in time. In the form presented here, it follows auditing practices in the accounting field, and indeed in such other fields as safety. Data is collected, typically with a checklist, analyzed, and presented to the organization for action. In the final analysis, it is the action that is important to human factors engineers, as the colliery example above shows. Such actions could be taken using other methodologies, such as active redesign by job incumbents (Wilson 1994); audits are only one method of tackling the problems of manufacturing and service industries. But as Drury (1991) points out, industry's moves towards quality are making it more measurement driven. Audits fit naturally into modern management practice as measurement, feedback, and benchmarking systems for the human factors function.

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