INCORPORATING HUMAN FACTORS IN CIM SYSTEM DESIGN

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Abstract. This paper provides an overview of the first phase of the human factors study undertaken by the Social and Applied Psychology Unit at the University of Sheffield within ESPRIT Project 534. The overall project aims to design, develop and evaluate an automated flexible assembly cell for the production of small-batch, high-precision aerospace components. This paper describes the progress and problems with the human factors study, with particular focus on the development of design criteria and a model of the design process. Future work is also outlined.

1. INTRODUCTION.

In most cases the design and implementation of advanced systems is undertaken with little consideration of the human, the end-user (Clegg and Corbett, 1986). Generally, technical systems are developed and installed by technical experts, and any attention given to the human aspects of the system, such as the role and skill requirements of operators, is essentially post-hoc (Blackler and Brown, 1986). The call for explicit consideration of the non-technical, human aspects of complex system design has, until fairly recently, largely been ignored (Damodaran, Simpson and Wilson, 1980).

The growth of the advanced technologies which have found application within the manufacturing industry (Spur, 1984) has prompted a reaction from the human sciences (e.g. Rohmert, 1985). These trends in advanced manufacturing have led to concerns about the human factors aspects of, for example, robotic systems (Salvendy, 1983; Noro and Okada, 1983, Shulman and Olex, 1985), computer-aided manufacturing (CAM) (Corbett 1985; Kemp, Clegg and Wall, 1984), integrated assembly systems (Kamali, Moodie and Salvendy, 1981), flexible manufacturing systems (Sharit, 1985; Rosenbrock, 1982), and computer-aided design (Van der Heiden and Grandjean, 1984). The future needs for, and the technical and economic implications of, computer-integrated manufacturing (CIM), have been well documented elsewhere (e.g. Ayres and Miller, 1982; Conaway, 1985; Northcott and Rogers, 1984) and are not the focus of this paper. The following sections of this paper provide brief details of ESPRIT project 534 and the Social and Applied Psychology Unit, and then outline the nature and importance of human factors, the project's objectives, and the progress made so far. The later parts summarise the lessons learnt and our future plans.

2. ESPRIT PROJECT NO. 534.

ESPRIT 534 (entitled "The Development of an Automated Flexible Assembly Cell and Associated Human Factors Study") aims to design, develop, implement and evaluate an automated flexible cell for the production of small-batch, high-precision aerospace components less than 1m cube. This five-year project has, from the outset, deliberately involved personnel from the areas of organisational and occupational psychology, ergonomics, and socio-technical systems analysis, in order to avoid a "technocentric" (Brodner, 1982) approach. There has been an integration of human factors considerations into the design of the flexible assembly cell to ensure that a 'parallel' design strategy (Clegg and Kemp, 1986) is followed. This was

in the clear recognition, by both development engineers and social scientists, that joint optimisation of technical and human criteria is a prerequisite for successful development and implementation of the factory CIM system (see Corbett, op cit).
There are 5 project partners, representing three countries, and a mix of academic and industrial organisations. These are:

- Westland PLC, who are the project managers, and are responsible for overall system design and integration, including the building of the demonstration cell;
- the MRC/ESRC Social and Applied Psychology Unit, concerned with the human factors aspects (see below);
- the Vrje Universiteit Brussel (VUB) responsible for the development of robotic assembly aspects, such as gripper design, manipulation and sensing; and
- Riso National Laboratory and Dantec Elektronic (Denmark) who are jointly designing the robotic system's vision capabilities, using analogue image processing techniques.

3. SOCIAL AND APPLIED PSYCHOLOGY UNIT.

The Social and Applied Psychology Unit (known as SAPU), based at the University of Sheffield, is a full-time research centre and is jointly funded by two UK research councils (the Medical Research Council and the Economic and Social Research Council). SAPU was founded in 1968, and has the overall objective of conducting research and development into psychological well-being and performance at work. Current work activities include studies of the psychological and organisational aspects of information technology in manufacturing industry, information technology in health and welfare services, job design and performance, occupational stress, career development and job transition, and cognitive ergonomics in computer-based systems. A total of 28 researchers and a number of support staff are currently employed at SAPU.

4. NATURE AND IMPORTANCE OF HUMAN FACTORS.

What do we mean by "human factors"? In our work with Project 534, we have made use of a rather broad definition of the term, in order to accommodate the variety of necessary disciplines addressing the human side of advanced manufacturing technology. Human factors can, thus, be regarded as a multidisciplinary science (including applied ergonomics, occupational psychology, human-computer interaction, etc.) which is concerned with designing for human use. Human factors in this broad sense is used to refer to the optimisation of working conditions (McCormick and Sanders, 1983), with the dual aim of enhancing the effectiveness and efficiency with which work is done, and of promoting certain human values within the work context (such as psychological well-being, health, and safety). We have, therefore, avoided much of the ambiguity which has stemmed from varied usage of the term on different sides of the Atlantic.
It should be stressed that the most advanced or complex systems will be ineffective if they are unfit for human use (Damodaran et al, op cit).
It is worth noting also that we are a long way from the "people-less" factory. To date, many of the abilities which humans offer, such as perceptual discrimination, the ability to learn and infer from experience, and to reason, make fine judgements, and cope with unforseen events and disturbances, are proving most difficult to simulate in automatic systems. The work devoted to the development of self-diagnostic systems illustrates this.
The general importance of the human aspects in relation to CIM (as an example of advanced industrial systems) is evidenced in, for example, USA programmes such as ICAM (see e.g. Howard, 1982).

5. HUMAN FACTORS OBJECTIVES.

Our overall objectives within the project are:

- "to include in the design process, consideration of the human factors aspects of Computer Integrated Manufacturing (CIM),
- to perform an evaluation of these aspects within the cell, and
- to provide a set of generalisable criteria for use in other manufacturing environments."

Thus, the tasks identified are: - examination of human factors in advanced manufacturing technology (AMT); specification of human factors criteria; identification of conflicts (between technical and human criteria); development of methods and measures; evaluation of the system; and, generalisation of the findings in the form of human factors criteria.

6. PROGRESS AND PROBLEMS.

a) The Approach. Our approach can be characterised as both iterative and interactive. We have conducted an analysis of the human factors of existing computer-aided manufacturing (CAM) systems (particularly flexible manufacturing systems), consulted experts in the area, and examined a growing body of literature on CAM and human factors.

Our development of human factors criteria attempts to be "prospective" (Corbett, op cit) or "socially proactive" (Brown and Newman, 1986) with respect to the system design. Thus, we sought to influence the design of the cell as early as possible. Accordingly, the criteria were drafted, prior to many important technical decisions, concerning, for instance, choice of software and cell layout. Furthermore, the incorporation of design criteria at this stage permitted consultation with the designers, leading to revisions of the criteria over time. There was early recognition that, for the successful incorporation of human factors into the process of system design, it is essential to work closely with those concerned with the technical aspects of the system.

The methods we have pursued in these initial stages have included visits to advanced manufacturing systems in the UK and Japan, systematic computer-based searches of the relevant literature, and the development of a general taxonomy (see below) for the study of the human factors considerations. The taxonomy relates closely to the divisions within the literature, and the current version separates our study into seven areas, which are not mutually exclusive. Safety and health issues are distributed across these areas as appropriate. They are:

- system design process;
- allocation of functions;
- job design;
- organisational structure;
- software ergonomics (human-computer interaction);
- hardware ergonomics;
- ergonomics of the environment.

A description of the topics encompassed within these areas is given in Ravden, Johnson, Clegg and Corbett (1986).

(b) Human factors criteria. The focus upon human factors criteria (also known as guidelines) by our group represents a concerted attempt to integrate, in a systematic manner, consideration of the human factors aspects in the development of the cell.

One of the primary goals of the human factors criteria is that they should be means of negotiating and debating pertinent issues, rather than producing them as a set of definitive statements - the latter role is probably more akin to that of a standard (Smith, 1986). A current trend within human factors is towards the use of criteria as aids to design (e.g. Simpson and Mason, 1983). This has led to a growing awareness of the problems faced in the application of such criteria (e.g. Mosier and Smith, 1986; Johnson, Clegg and Ravden, 1986).

latter is seen as a useful tool in the interfacing of human factors and engineering, with the recognition that it is a simplified, idealised representation of the process.
With the production of criteria for "good" human factors, we discovered that they must also be subject to our own human factors criteria (Johnson et al., op cit). For instance, they should be structured in a usable and useful way, and take account of user preferences.

8. FUTURE WORK.

The next part of our study will refine and revise the criteria, making sure that they are, wherever possible, linked to appropriate phases of the design process. The engineers are to co-operate in the identification and further detailing of the activities undertaken within phases of the process. Much of this work will ensure that trade-offs and conflicts between criteria (whether human or technical) are made explicit.
With respect to future work on the system design, our intention is to involve potential users. This will enable us to gather valuable information about the system, based on the insight of current operators of computer-aided manufacturing systems. This is one of the most important steps, and will also provide a means of feedback on the design criteria and general ease-of-use issues.
Finally, we will employ the criteria as a basis for developing evaluation measures for CIM. Then we will seek to convert these into general design criteria and associated methods and measures for use within other CIM developments. Thus, the goal is to produce a set of human factors tools to influence CIM system design, and to facilitate an overall human factors evaluation.

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10. ACKNOWLEDGEMENTS.

We would like to express our gratitude to all of the partners in ESPRIT Project 534, and in particular to those at Westland who have assisted us with our efforts.

NOTE:
This paper is based on a presentation made to the ESPRIT Technical Workshops, Special Interest Group III ("Human Factors in CIM"), Brussels, Belgium (September, 1985) as well as subsequent ESPRIT 534 progress.

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May 1986.

Published by -
CIM Europe, ESPRIT, Brussels; as Occasional Paper No.2,
for SIG (Special Interest Group) III on Human Factors in CIM.
(SAPU MEMO. NO. 815)