Engineering Psychology and Cognitive Ergonomics Volume Five

Aerospace and Transportation Systems

Edited by
Don Harris

Ashgate

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Acknowledgements

I must express my thanks to all the people who contributed, either directly or indirectly, to making a success of the Third International Conference on Engineering Psychology and Cognitive Ergonomics. Without these people neither the conference nor these volumes would have been possible. Firstly, I must thank all the people in the Human Factors Group at the College of Aeronautics, Cranfield University would worked so hard preparing for the conference and helping to run it. My thanks go out to Tricia Jolly, Sarah Quinn, Paul Robertson, Rebecca Stewart and Lauren Thomas. In addition I should thank Peter Jolly and my wife, Fiona for providing a little extra, unpaid 'muscle' when required. I would also like to thank the Head of the Human Factors Group, Prof. Helen Muir for her continued support of the conference and all the other members of the Group who were not directly involved with the conference but had to tolerate all the disruption on the run up to the big day! Once again, I must mention the assistance provided by John Hindley and all the other staff from Ashgate who do so much in terms of helping to support the conference and in the preparation of these volumes. Last but certainly not least, my gratitude goes to all the authors for delivering their papers at the conference and supplying the manuscripts that make up these volumes. Without them, the conference and these books would not be possible. If I have omitted anyone from this list I apologise now, however, they can rest assured that that their contributions were most appreciated.

Don Harris
Cranfield University
December 2000

Preface

The papers in this book are all derived from presentations made at the Third International Conference on Engineering Psychology and Cognitive Ergonomics held in Edinburgh, between 25-27 October 2000. Over 100 papers were presented in up to four parallel sessions, attracting authors from 15 countries.

This book is the first of a set of two volumes of papers presented at the conference. The papers in this volume are all concerned with transportation applications. The papers in the companion volume are concerned with job design, product design, human-computer interaction and applied cognitive psychology. Both books are organised around the application areas in which the work was conducted. As anyone at the conference will tell you, the way the papers are arranged in these books bears no resemblance whatsoever to the structure of the sessions at the conference itself. As a result, some authors may be slightly surprised about where they find their paper!

The first section of this volume, concerned with aerospace ergonomics, opens with a paper derived from the keynote address given to the conference by Raja Parasuraman from the Catholic University of America. This paper describes some of the implications for safety arising from high levels of automation, which paradoxically, has often been implemented in an attempt to increase the overall safety of the system. While the first section of the book is concerned with the airborne components of the aerospace system, the second section is devoted to the ground-based aspects of the system – air traffic control. In contrast to the opening section of the book, in which the emphasis is placed upon the equipment, the third section of the first volume (Aerospace Psychology) focuses human on the human component of the system.

Section four of the book moves away from the aerospace sector and is dedicated to the driver and the equipment found in road vehicles. It will be noted, though, that a great deal of technology initially developed in the aerospace sector is now being further adapted for installation into road vehicles.

The fifth and final section of the book is concerned with railway travel. This section opens with John Wilson's keynote address to the conference, which took a broad overview of the problems facing the rail industry stemming from human factors deficiencies in the system. To put the conference and papers into an historical context, the day before the conference opened the East Coast mainline was closed as a result of safety concerns about the state of the permanent way. These themselves were a direct product of the fatal accident at Hatfield which had happened the week before. The papers on railway safety suddenly became very topical!

Once again, I must extend my thanks to all the contributing authors. Their efforts are much appreciated.

Contents

Part One
AEROSPACE COGNITIVE ERGONOMICS

1 Application of human performance data and quantitative models to the design of automation

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Abstract

Automation is pervasive in industry, medicine, transportation, and many other systems. Unfortunately, the benefits of automation are often not realised in operating systems. Certain automation designs can also compromise safety. However, human performance data from empirical studies can provide guidelines for designing automated systems that can be used effectively and safely by human operators. Human performance consequences such as mental workload, situation awareness, trust, skill retention, etc. constitute primary criteria for evaluating different automation designs. Computational and formal models of human interaction with automation can also inform automation design. Human performance data and quantitative models thus provide an objective basis for designing automation for effective, safe human use.

Introduction

Automation is being increasingly implemented in industry, medicine, air, ground, and maritime transportation, and other domains (Parasuraman and Mouloua, 1996). Despite the many advantages that automation can provide, the anticipated benefits have not always been realised in full, and in some cases safety has been compromised (Billings, 1997; Parasuraman and Riley, 1997). Operational experiences and research studies have led to the realisation that automation can fundamentally change the nature of the cognitive demands and responsibilities of the human operators of systems, often in ways that were unintended and unanticipated by designers (Bainbridge, 1983; Parasuraman and Riley, 1997; Wickens, Mavor, Parasuraman and McGee, 1998; Wiener and Curry, 1980; Woods, 1996). These changes can limit the effective use of automation by humans, thereby undermining efficiency and, potentially, safety.

Ergonomists routinely point out that automation should not be designed only on the basis of technical guidelines as proposed by engineers. But equally, automation design should not be guided *solely* by qualitative studies, field experience, or the opinions of ergonomics experts. Rather, *empirical research* on human-automation interaction must be drawn upon to guide design. There is now an extensive body of empirical work on human performance in automated systems, including cognitive theory, laboratory experiments, simulator studies, field studies, incident analyses and accident investigations (Billings, 1997; Parasuraman, 2000; Parasuraman and Riley, 1997; Rasmussen, 1986; Sarter, Woods and Billings, 1997; Scerbo and Mouloua, 1999; Sheridan, 1992; Wickens et al., 1998; Wiener, 1988). This knowledge base is now mature enough to be applied to the design of efficient and safe automated systems. Empirical studies under controlled settings, supplemented by field observations, are necessary to derive principles that can be used to design effective automation. At the same time, empirical studies can be more effectively translated into design practice if they are complemented by quantitative models of human-automation interaction. This chapter describes both approaches.

Human performance data

It has been suggested that automation must be designed to be *human-centred*. There are many meanings of this term (see Wickens et al., 1998). The definition proposed by Billings (1997), 'automation designed to work co-operatively with human operators in pursuit of stated objectives,' emphasise that automation functionality should be designed to support human performance and human understanding of the system (see also Riley, 1997). Billings (1997) suggested a number of broad requirements for human-centred automation, beginning with the axiom that operators must remain in command of the system. From this axiom he drew several corollary principles. Chief among them is that the operator must be actively involved in the system and adequately informed about the status of the automation. Billings (1997) also proposed that humans and automation must understand each other's intent in complex systems.

There is general support for these tenets from operational experience and incident analyses. The goal of human-centred automation can also be reached if automation is designed to minimise human performance costs and maximise human performance benefits. Over the past two decades, researchers have examined a number of different aspects of human interaction with automated systems and documented both the beneficial and negative effects on human performance (Parasuraman and Riley, 1997; Sarter et al., 1997; Wiener, 1988). By examining the human performance costs of certain automation designs, it will be possible to consider alternative designs that mitigate those costs. Although many different aspects of human performance have been examined, most empirical research has focused on four areas, mental workload, situation awareness, trust, and skill degradation.

Designers often intend automation to reduce operator workload. Yet certain forms of automation increase operator workload, or produce an unbalanced pattern of workload over time. These mostly involve automation that is difficult to initiate and engage, thus increasing both cognitive workload (Kirlik, 1993) and if extensive data entry is required, the physical workload of the operator. Unfortunately, examples abound in aviation (e.g., the flight management system) and other industries of automation that was originally implemented in an effort to reduce operator workload but in fact did not do so, or merely redistributed workload (Wiener, 1988).

High-level automation of decision-making functions may also adversely affect the operator's awareness of the system and of certain dynamic features of the work environment (Endsley, 1999). Humans tend to be less aware of changes in environmental or system states when those changes are under the control of another agent (whether that agent is automation or another human) than when they make the changes themselves (Endsley, 1999; Endsley and Kiris, 1995; Kaber, Omal and Endsley, 1999; Sarter and Woods, 1995). If decision-making automation consistently and repeatedly selects and executes decision choices in a dynamic environment, the human operator may lose situation awareness because he or she is not actively engaged in evaluating the information sources leading to a decision. The, 1995 crash of a Boeing 757 near Cali, Colombia was cited as exemplifying the adverse effect an automated navigation system can have on the pilot's situation awareness (Endsley and Strauch, 1997).

The effects of automation on operator workload and situation awareness will also depend on the operator's trust in automation, particularly when using decision aiding and planning systems. Most automated systems are highly but not perfectly reliable in selecting and executing decision choices. Consequently, the operator may not monitor the automation and its information sources and hence fail to detect the occasional times when the automation fails (Parasuraman, Molloy, and Singh, 1993) or when the context does not match the assumptions made by the decision aid's internal logic (Layton, Smith, and McCoy, 1994). This phenomenon, known as automation complacency (Billings, Lauber, Funkhouser, Lyman and Huff, 1976; Parasuraman et al., 1993), can be attributed to an attention allocation policy driven by the operator's trust that the automation is reliable and will continue to be so in the future (Lee and Moray, 1992). The finding that complacency can be abolished when automation behavior is inconsistent due to variable reliability (Parasuraman et al., 1993) provides support for this view. Automation complacency has been implicated in several transportation incidents and accidents. A recent example was the 1995 grounding of the cruise ship *Royal Majesty* off the coast of Nantucket, Massachusetts. The accident occurred following the failure of a satellite-based automated navigation system and because the crew did not monitor other sources of position information (National Transportation Safety Board, 1997).

If complacency reflects inappropriate trust in automation, the converse, distrust in automation, can also occur. Often this may occur with automated alerting systems that give frequent false indications of a hazard, as in the early version of an airborne safety system, the Traffic Alert and Collision Avoidance System (TCAS) (see Parasuraman and Riley, 1997). The appropriate *calibration* of trust between the extremes of complacency and distrust is an important challenge that may require new approaches to operator training (Cohen, Parasuraman and Freeman, 1997).

Finally, if the decision-making function is consistently performed by automation, there will come a time when the human operator will not be as skilled in performing that function (Kaber and Riley, 1999; Wiener, 1988). Degradation of cognitive skills may be particularly important following automation failure, if the human operator is required to use those skills to serve as a 'back up' to the automation.

Quantitative models

Human performance findings can provide a more principled approach to automation design than design that is based solely on the expert opinion of human factors professionals. Nevertheless, the recommendations one can make using this approach remains qualitative in nature. Qualitative recommendations could be strengthened if supplemented by quantitative models of human-automation interaction. Several computational models have been put forward very recently. Some of the models are *normative* models that have been previously applied to the evaluation of decision-making performance. Others can be characterised as cognitive or behavioural models.

Normative models

Among normative models are those based on signal detection theory (SDT), Bayesian analysis, and expected value models. A number of authors have pointed to the limitations of normative models (e.g., utility theory) as models of human decision-making (e.g., Kahneman, Slovic, and Tversky 1982; Klein 1989). Nevertheless, such models may be applied usefully to address issues pertaining to the design decision to automate. The signal detection and Bayesian models have been primarily examined in relation to automated alerting and warning systems such as TCAS (Kuchar, 1996). Parasuraman, Masalonis and Hancock (2000)