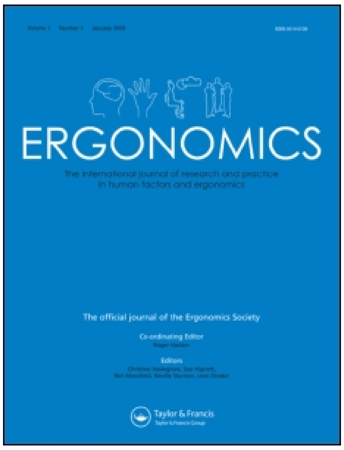

Ergonomics
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713701117

The ergonomics of command and control

Neville A. Stanton [a]; Chris Baber [b]
[a] School of Engineering and Design, Brunel University, Uxbridge, Middlesex, UK [b] School of Electrical, Electronic and Computer Engineering, University of Birmingham, Edgbaston, Birmingham, UK

To cite this Article Stanton, Neville A. and Baber, Chris(2006) 'The ergonomics of command and control', Ergonomics, 49: 12, 1131 — 1138
To link to this Article: DOI: 10.1080/00140130600612523
URL: http://dx.doi.org/10.1080/00140130600612523

Ergonomics
Vol. 49, Nos. 12–13, 10–22 October 2006, 1131–1138

Taylor & Francis
Taylor & Francis Group

Editorial

The ergonomics of command and control

NEVILLE A. STANTON*† and CHRIS BABER‡

†School of Engineering and Design, Brunel University, Uxbridge, Middlesex UB8 3PH, UK
‡School of Electrical, Electronic and Computer Engineering, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK

1. Introduction

Since its inception, just after the Second World War, ergonomics research has paid special attention to the issues surrounding human control of systems. Command and control environments continue to represent a challenging domain for ergonomics research. We take a broad view of command and control research, to include C2 (command and control), C3 (command, control, and communication), and C4 (command, control, communication, and computers) as well as human supervisory control paradigms. This special issue of *Ergonomics* aims to present state-of-the-art research into models of team performance, evaluation of novel interaction technologies, case studies, methodologies, and theoretical review papers. We are pleased to present papers that detail research on these topics in domains as diverse as the emergency services (e.g. police, fire, and ambulance), civilian applications (e.g. air traffic control, rail networks, and nuclear power), and military applications (e.g. land, sea and air) of command and control. While the domains of application are very diverse, many of the challenges they face share interesting similarities.

Smalley (2003) recently proposed a model of C2, comprising 10 control modes:

- primary situation awareness
- planning
- information exchange
- tactical situation reports
- current situation awareness
- directing plan of execution
- system operation
- system monitoring
- system status
- internal coordination and communications.

*Corresponding author. Email: Neville.Stanton@brunel.ac.uk

Ergonomics
ISSN 0014-0139 print/ISSN 1366-5847 online © 2006 Taylor & Francis
http://www.tandf.co.uk/journals
DOI: 10.1080/00140130600612523

In contrast, Sheridan (2002) identified the main aspects of human performance in human supervisory control systems (e.g. decision-making, situational awareness, trust, workload, and human error). He presented the roles of the human supervisor in a linear five-stage model, arguing that these roles offer a generic model of human supervisory control and that the roles are 'more or less causal and temporal in order' (Sheridan 2002, p. 118):

- planning
- teaching
- monitoring
- intervening
- learning.

Both models assume that before engaging with the automatic systems, people need to plan what is done. When engaging with the system, people need to tell the system what it needs to do through some form of information exchange. Most of the time, people (commanders and supervisors) are monitoring the tasks performed by others and/or an automatic system. This requires the acquisition, development, and reporting of situation awareness of the system state. If errors or failures are detected in the system, people are required to intervene and correct the situation. Finally, people need to learn from their experience of interacting with systems. These models can be applied to the design, operation, evaluation, and maintenance of systems.

In a special issue of *Ergonomics* on teamwork, Annett and Stanton (2000) argued that the contemporary issues include the structure of the team, training of the team, and development of the human–machine interface. These issues are particularly pertinent to command and control research as teamwork is a major factor. An experimental study of technologically mediated command and control activities focused on the effects of location of team members, communication medium, and type of command and control task on the performance of the team (Stanton *et al.* 2002). The study showed that all these variables interact such that some tasks are better performed remotely whilst others are better performed face-to-face, and that some tasks are better suited to one communication medium rather than another. It is these subtle interactions that are difficult to predict in designing command and control environments. Therefore optimal performance of command and control environments is bound to place a strong reliance on experimental ergonomics research for socio-technical systems design.

2. Contributions to the special issue

We have opted to group contributions to the special issue under four main categories: system design, theoretical development, workload and situation awareness, and methodological developments. Within these categories, there are a variety of domains and approaches, as indicated previously.

2.1. *System design*

Within any C2 system, a significant challenge relates to the design and use of information displays. In this special issue, there are two papers which consider information design and use from the perspectives of software engineering, field study, and experimentation.

Riley *et al.* focus on the design of systems to support shared manoeuvres planning processes in Army land-battle situations. Using a battery of cognitive task analyses, they identified a number of key challenges to design of information displays. For example, the time available to develop plans and the reliability of intelligence combine to make planning problematic. In particular, the 'missing information' might need to be supplied from assumptions concerning the activity and intent of the enemy, and from new intelligence becoming available during the course of operation. These problems are compounded by the need to collaborate during planning, often across a range of specialisms and locations. This paper proposes a suite of tools that could support this notion of planning: for example, sharing information in a variety of forms, mechanisms that facilitate critical thinking and contingency analysis during planning, and maintaining awareness of both current and past activities or tasks of other members in the dispersed team. The paper concludes that these tools could be beneficial in a wide range of domains.

Thomas and Wickens consider the design of terrain displays that might be used by tank commanders. The paper reports an experiment using computer-generated terrain displays which were either 'tethered', i.e. a three-dimensional exocentric view, or 'immersed', i.e. a three-dimensional egocentric view presented from the perspective that the commander would have at eye level (2 metres above the ground) from his/her location within the environment together with a two-dimensional inset map. The study showed that the tethered display produced the highest level of performance on all tasks, and that although an immersed display that required manual panning produced performance almost as high as that in the tethered display, performance deteriorated on tasks involving integration between two views. This suggests that participants were cognitively tunnelling on the compelling three-dimensional view and not attending to information in the two-dimensional inset map. A further finding was that, compared with manual panning, automated panning hindered performance.

2.2. *Theoretical developments*

Ergonomics has always sought to incorporate contemporary thinking into its research, and three papers in this special issue show how C2 research can exploit ideas emerging from distributed cognition, social network analysis and speech act theory.

Furniss and Blandford consider medical emergency dispatch. Their paper employs distributed cognition and contextual inquiry to analyse observations about control room operation. In particular, the paper focuses on a physical model which considers the layout of the control room and the elements supporting shared access to information; an information flow model which considers communication between individuals; and an artefact model which considers the ways in which different objects support cognition (e.g. work-cards, screen designs, etc.) On the basis of this analysis, the paper considers two scenarios in which the physical layout or the artefacts used could be redesigned and how this might affect performance.

Houghton *et al.* argue that social network theory and associated analysis methods have a valuable part to play in the study of command and control teams. Social network analysis can be used to study both networks that have been formally designed and those that form ad hoc. Social network analysis also offers both qualitative (in terms of the graphical representation of linked nodes in a network) and quantitative (in terms of mathematical metrics computed from graph theory) analyses of communication networks. Houghton *et al.* illustrate examples of both analyses with reference to prior research on social communication and military command and control. Two particular mathematical metrics are employed, centrality (i.e. the distance of one node from all other nodes in the network) and sociometric status (i.e. the prominence of any nodes in the network). To demonstrate the usefulness of social network theory, Houghton *et al.* investigated the networks for three scenarios in the Fire Service and another three scenarios in the Police Service. Social network analysis was used to characterize these scenarios into three basic types, demonstrated with both the qualitative (in terms of the graphical representation of three distinct network) and quantitative (in terms of mathematical metrics of centrality and sociometric status) analyses. They argue that the representation of the networks in this manner allows for both subjective and objective questioning and assessment of the structures, particularly as some network structures appear to be more effective in some scenarios than others.

Svensson and Anderson consider team communication among fighter pilot controllers performing a simulated mission. Their analysis categorizes the communications into particular types of speech acts and communication problem. The findings indicate how performance interrelates with type of speech act and type of activity. In particular, they show that speech act frequency (especially meta-communications and tactics) was highest during good performance. Communication problems typically related to simultaneous speech. The paper demonstrates that, in order to work efficiently, team members need not only to communicate, but also to communicate sufficiently and at the appropriate times.

2.3. *Workload and situation awareness*

The complexity of C2 operations typically places high demands on operators working within it, and can cause problems with maintaining sound levels of situation awareness. In this special issue, workload is explored through three approaches to modelling, and two new approaches to considering distributed situation awareness are explored.

Grootjen *et al.* propose a cognitive task load model and associated methodology to analyse workload in future C2 environments. The theoretical model comprises three independent factors: time occupied, task-set switching, and level of information processing. From this model, they are able to predict extreme operation conditions of task underload and task overload. They are also able to anticipate the configuration for optimal task loading. In an experimental task on a naval ship command room simulator, each of these factors was systematically manipulated in order to analyse human performance under the extremes of task loading. Justification for the research came from the ever-increasing levels of automation and the need to manage more complex, and demanding, systems with fewer personnel. The results suggest that it was difficult for the researchers to manipulate the time occupied variable in a sensitive manner, whereas the manipulations of task-set switching and level of information processing were more sensitive. The model was able to predict the effects of manipulating task load on these two variables successfully.

Gregoriades and Sutcliffe also consider workload. In their paper, they consider the relationship between communication load and workload on frigates. In particular, the paper describes a tool and method for scenario-based workload assessment. Workload is assessed in terms of the communication and task load that each agent is able to handle. The method employs subjective task and communication estimates used to calculate the workload of human operators, using static and scenario-based analyses. This enables the identification of bottlenecks to be addressed by the designer with the appropriate allocation of function between humans and smart technology. This task is supported by the functional allocation advisor tool.

Stanton *et al.* propose a new theory of distributed situation awareness for collaborative teams. The theory aims to overcome some of the limitations of scaling up theories of individual situation awareness to distributed teams. Distributed situation awareness states a macro, rather than a micro, view of situational awareness to encompass the whole system under analysis. This means that a higher level of analysis is applied than has previously been the case. This has meant that a new methodology is required to gather the situation awareness data and represent it at a systems level. In order to illustrate the ideas of distributed situation awareness, a case study of a C2 team from a frigate command room was presented. The situational awareness data were extracted from subject matter experts using critical decision interviews and hierarchical task analysis. These data were then analysed using content analysis, and then represented as knowledge concepts in a propositional network. The knowledge concepts were then coded to the stage of activity in which they were activated. Key knowledge concepts (i.e. those that were central to the activities) were then identified and put into a table. It was argued that the distributed situation awareness theory and associated methods offered a unique insight into the knowledge demands placed on a system. This information could then be used to examine system workload, to design training systems and user interfaces, to allocate system functions, and to model new systems.

Gorman *et al.* take case studies from the Gulf War to consider distributed situation awareness from a different perspective. The paper focuses on the challenge of decentralized command and control, with a particular emphasis on what the concept of team situation awareness might mean in this setting. A theoretical framework for a process-based measure called Coordinated Awareness of Situations by Teams (CAST) is outlined and developed. In particular, the CAST measurement uses the concept of 'roadblocks'. If it is assumed that a distributed C2 system follows a 'trajectory' in accordance with specific goals, then something that interrupts this trajectory could be a roadblock. As the team responds to roadblocks, it is possible to gain insight into the processes of perception and action that the team needs in order to navigate around it. This provides an insight into team situation awareness.

2.4. *Methodological developments*

Methodological developments in command and control research focus on describing, analysing, and evaluating the activity of, and the interactions between, the agents in the command and control system. One paper looks at the ability of agents to recover from system failure, two papers take ethnographic-type approaches to assessing contemporary systems, one paper focuses on the methodology for analysing decision making, and the final paper focuses on the development of an emergency response planning simulator for investigations into multi-agency command and control.

Shorrock and Straeter argue that automation will play an increasing role in system operation and that, since automation will have some inherent failures, methods for understanding how human operators will recover these systems are required. They suggest that this need is even more urgent as systems become more intelligent and start to play a role in prediction, problem-solving, decision-making, and task sequencing and scheduling. Shorrock and Straeter are admittedly considering worst-case scenarios, but they argue that it is inevitable that software will fail because of design, coding, or maintenance error, or because the system is used outside its original specification. They began their study of human recovery of systems by interviewing air traffic management personnel to find out how they recover systems from failure. From this analysis they developed a framework for analysing human recovery, called the Recovery from Automation Failure Tool (RAFT), comprising five main phases: the cause, the nature of the problem, the effect, the recovery process, and the outcome. The recovery process is broken down into detection of the fault, interpretation of the situation, diagnosing the cause, mitigating the consequences, and correction of the fault. Shorrock and Straeter propose that RAFT can be used to structure group discussion on the recovery process for any imaginable failure scenario.

Walker *et al.* propose the Event Analysis of Systemic Teamwork (EAST) methodology as an approach to the analysis of command and control activity. The methodology integrates five ergonomics methods (hierarchical task analysis, observation, coordination demand analysis, communications usage diagram, and critical decision interview) to produce the data necessary for three network representations of the system under investigation: a propositional network, a social network, and a task network. Walker *et al.* argue that this data collection, analysis, and representation characterizes the important aspects of the system, namely which agents are participating, which tasks are being performed, where agents are located, how the agents collaborate, and what knowledge is being used and shared. They show how the methodology is applied in a case study of three scenarios from the UK rail industry. Demonstration of the output for the EAST methodology is provided together with some justification for application to other domains.

Farrington-Darby *et al.* present their finding of the application of an ethnographic-type investigation into the work domain of controllers in Network Rail. They argue that there is a need to understand all aspects of the domain under analysis, and this is part of a more general move within the ergonomics discipline to understand the context of work as well as the work itself. They propose the participant–observer method as an approach that affords the researcher a first-person perspective of the work and surrounding physical, psychological, social, cultural, and political environment. The participant–observer method has the potential to allow the researcher to develop a rapport with the group of people under investigation. Farrington-Derby *et al.* propose five phases of analysis: (i) general familiarization, (ii) initial observations, (iii) collection of evidence, opinion, beliefs, and understanding through participation and interviews, (iv) data compilation, analysis, reduction, and representation, and (v) data qualification and validation with participants and subject matter experts. The results of the method are a descriptive and qualitative account of the key features of the work domain, in this case that of railway controllers. The researchers argue that the qualitative account can point to areas that require further investigation within the work domain. Although Farrington-Derby *et al.* confess that their approach is not pure ethnography, they point out that the method did require spells of immersion in the work domain and provided the researcher with some unique insights into the social aspects of the controllers' work.

Patrick *et al.* show how process training methodology can be used to map out team activities in problem detection and problem diagnosis phases of training. For the purpose of the study, the researchers investigated team training in a full-scope nuclear power plant control room simulator. Patrick *et al.* argue that the process tracing method helps focus the analysis on the behaviour of the team without losing relevant situational and contextual information. The process tracing methodology enables researchers to map team reasoning against a timeline. The four main phases of the method are (i) collection of data via video, protocols, interviews, and observations, (ii) transcribe data onto a timeline, (iii) code data into segments according to the scheme used, and (iv) analyse and interpret the data and coding. The training scenarios required the teams to carry out a routine maintenance activity in which a minor disturbance was presented. Failure to detect the symptoms, which were symptomatic of something less benign, would lead a more serious event. Patrick *et al.* found that there were differences within and between teams in terms of the time allocated to different activities over the phases of operation of the power plant. The process training method was used to show both quantitative and qualitative differences in team performances in a graphical manner.

Ntuen *et al.* present work on the development of a simulated environment for studies of distributed collaborative multi-agency activities in emergency response planning. They argue that there are serious flaws in emergency response systems, which are only revealed under extreme circumstances. They cite the recent case of Hurricane Katrina in New Orleans as an example of where shortcomings in anticipation, preparation, planning, rehearsal, and response activities were exposed. Ntuen *et al.* identify many factors that are pertinent to the success or failure of emergency responses, such as the form of incident command structure, inter-operability between hard and soft command systems, adequacy of plans and contingencies, collaboration between military and civilian task forces, and dynamic prioritization of rescue operations. They argue that simulation and testing of systems and scenarios can help to develop an understanding of the complex interactions between these many system variables. Ntuen *et al.* apply a cognitive systems engineering approach to the problem, combining the methodologies of Endsley, Rasmussen, and Vicente to produce a work domain analysis of the emergency response systems. This was used as the basis for the development of a prototype simulation of a decision support system for training in emergency response scenarios. Ntuen *et al.* describe the function of the software system and they plan to use it for investigations into planning, analysis, and execution of distributed multi-agency emergency response scenarios.

3. Conclusions

The papers in the special issue provide a contemporary overview of the status of ergonomics research, and research trends, in command and control. Whereas one might characterize research in command and control in the 1990s as aiming towards the development of system models, in which humans could be described as sophisticated system components, the papers in this special issue all appear to take the role of humans to be central and distinct from other aspects of the system. Thus, although there is an overarching conception of command and control 'systems', the papers consider the peculiarities of the roles adopted by humans. This is particularly true of those papers which make use of field observations of real people performing real command and control activities. There seems to be an unspoken renaissance of a socio-technical approach to command and control research, in which both social and technical domains are given equal importance, and there is a keen desire to understand how these domains interact. The following general principles can be drawn from the research presented in this special issue.

1. Systems need to be flexible to adapt to new ways of working or they can quickly become redundant.
2. The relationships between qualitative and quantitative aspects of system performance need to be understood.
3. Synchronization of communication between system agents needs to be coordinated if performance is to be optimized.

4. Predictions (and validations of those predictions) of system performance are a necessary prerequisite to design.
5. Care needs to be taken in deciding which tasks, under which conditions, are scheduled to non-human agents.
6. Comprehensive understanding of contemporary command and control systems requires naturalistic approaches.

Modern approaches to socio-technical theories and methodologies are contained within the papers. These approaches will undoubtedly lead to new ways of thinking about command and control, which itself will inform the design of future systems.

References

Annett, J. and Stanton, N.A., 2000, Team work: a problem for ergonomics? *Ergonomics*, **43,** 1045–1051.

Sheridan, T., 2002, *Humans and Automation: System Design and Research Issues* (New York: Wiley).

Smalley, J., 2003, Cognitive factors in the analysis, design and assessment of command and control systems. In *Handbook of Cognitive Task Design*, E. Hollnagel (Ed.), pp. 223–253 (Mahwah, NJ: Lawrence Erlbaum).

Stanton, N.A., Connelly, V., Prichard, J. and van Vugt, M., 2002, Assessing the effects of location, media and task type on team performance. *Journal of Defence Studies*, **7,** 29–41.