WORK DOMAIN MODELS FOR COGNITIVE ERGONOMICS: AN ILLUSTRATION FROM MILITARY COMMAND AND CONTROL

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There is general agreement that 'work' is a primary concept for Cognitive Ergonomics (CE). However, there is little agreement how the domain of work might best be modelled. This paper assesses two contrasting approaches to such modelling. The first, and implicit approach, derives from domain experts. The second, and explicit approach, derives from domain research. The approaches are illustrated by an initial analysis of the domain of military command and control and specifically of models of the Vincennes incident. Implicit and explicit domain models are assessed in terms of the incident events. It is concluded that both models have potential to support design, but the explicit model also has potential to support research. The need for explicit domain modelling to support validation of CE design knowledge is underlined.

Introduction

There is general agreement that for Ergonomics, and in particular for Cognitive Ergonomics (CE) – the concern here – 'work' is the primary concept, expressing its scope. Ergonomics was originally derived from two Greek words: 'ergos' meaning work and 'nomos' meaning (natural) laws, and so 'laws of work' (Murrell, 1971). Work, domain, environment etc. reflect Ergonomics' and so CE's concern with work (Murrell, 1971; Card et al., 1983; Long 1987; Galer, 1989; Carroll, 1991; Pheasant, 1991; Dix et al., 1993; and Oborne, 1994). There is also agreement as to the other primary concepts of CE, for example users, technology and performance etc. (Flach, 1998; Vicente, 1998; and Long 2001). However, there is little or no agreement as to how the domain of work should be modelled for CE design and research. Two contrasting approaches can be discerned.

The first, and implicit, approach derives from domain experts (Murrell, 1971; Card et al., 1983; Galer, 1989; Pheasant, 1991; Dix et al., 1993; and Oborne, 1994). These experts are highly knowledgeable about individual domains of work and their knowledge informs CE design and research. The second, and explicit, approach derives from

research into domain models (Dowell and Long, 1998; Flach, 1998; and Vicente, 1998). Domain models represent work explicitly.

The aim of this paper is to assess implicit and explicit domain models for CE design and research. The assessment is based on an illustration, taken from an initial analysis of the work domain of military command and control (C^2) and specifically as embodied in the Vincennes incident.

Illustration: the Vincennes Incident

The Vincennes incident was widely reported (see The London Times, 4 and 5 July, 1988; and Time Magazine, 18 July 1988) and was also the object of an official report (USDoD, 1988). The incident took place during the Iran/Iraq war, initially a land battle. In the late 1980s, Iraq attempted to disrupt Iran's oil trade. Iraq launched air attacks against Iranian oil installations. Iran's response was to disrupt oil transport in the Persian Gulf. The US response was to send naval forces to ensure oil supplies. The incident occurred on the morning of 3 July, 1988. The Iraqi Air Force had successfully attacked Iranian forces near the North Persian Gulf. Iranian retaliation of small boat attacks on commercial shipping was expected. The incident occurred when the USS Vincennes mistakenly shot down civilian Iran Air Flight 655, while simultaneously engaging a group of Iranian small boats.

Implicit Domain Model

The domain of work here is that of C^2. The main sources of information about C^2 are military domain experts using C^2 systems. Here, the C^2 model is implicit in the experts' descriptions of the Vincennes incident in the official report. A selection is summarised in the left column of Appendix 1.

The incident events are described in C^2 systems expert language. For example: "0649 Flight 655 adopts its flight path, which is toward the Vincennes. The Vincennes challenges its air contact (actually Flight 655), but receives no reply". The language comprises both ordinary expressions ("receives no reply"), as well as technical expressions ("Flight 655 adopts its flight path"). However, neither expresses C^2 explicitly, only in the specific terms of the events. Further, C^2 domain aspects ("The missiles destroy Flight 655") and C^2 system aspects ("Vincennes' air contact appears electronically to identify itself as a military aircraft") both appear, but are not distinguished. The domain of the Vincennes incident is undoubtedly that of C^2, derived from experts, but the model of C^2 remains implicit. The model informs the experts' explicit descriptions, but is not itself explicit.

Explicit domain model

The domain of a worksystem is the work it performs (Dowell and Long, 1998). The domain comprises objects, constituted of attributes, having values. A worksystem comprises interactive user and device behaviours, which, when executed, perform tasks effectively (transforming the domain, so to achieve desired goal states). Here, C^2 performs two types of work, and so is modelled as two domains: the domain of plans for

armed conflict and the domain of armed conflict. The domain of plans comprises a single object – an **interest** – with a single attribute – **security** (model concepts are in bold initially). An interest specifies a use of resources by a nation state. Uses may be political, military etc. Resources include the land, sea, air, space and installations etc. Security is the potential to realise an interest.

Within the domain of armed-conflict (military operations), the domain objects are identified as: **friends**, **enemies** and **neutrals**. These objects are distinguished by the ends pursued. A friend supports the interests pursued by C^2. An enemy, in contrast, pursues incompatible interests. Neutrals pursue interests, compatible with those of both friends and enemies. The domain also comprises a **resource** object, whose use attribute is interest. The three classes of participant object exhibit between them attributes of **power**, **vulnerability** and **involvement**. Power, here, is the potential to secure interests by the display of force.

One participant's potential to damage another implies the latter's weakness. That is, power implies vulnerability. The power of one participant, and the reciprocal vulnerability of another, implies the involvement. Friends and enemies may exhibit power/threat, vulnerability and involvement. Neutrals, in contrast, only exhibit vulnerability and involvement (for a complete description, see Colbert and Long , 1995).

This explicit domain model of C^2 was used to model the Vincennes incident. A selection from the application is summarised on the right of Appendix 1. Domain concepts are in bold. The appendix shows how the concepts are able to describe the domain transformations of the left column. For example, "The small boats and the Vincennes continue to close" is expressed by the domain model as: "The **involvement**, **power** and **vulnerability** of the **friend** (Vincennes) and the **enemy** increase again". The appendix also demonstrates the explicitness of the concepts – by their identification. Finally, the model expresses only the transformations of the domain, not the behaviours of the C^2 worksystem.

Domain model assessment

Both CE domain models, implicit and explicit, constitute CE design knowledge, intended to support design and research. CE design can be conceived as the diagnosis (of design problems) and the prescription (of design solutions) (Long, 2001). CE research can be conceived as the acquisition and validation of design knowledge (Long, 2001). Implicit and explicit models are now assessed for their potential to support design and research.

The implicit model of C^2 would appear to have potential to support design as both diagnosis and prescription. For example: "Flight 655's altitude is misread. The air contact is perceived as diving towards the Vincennes; in fact, it is climbing away from it". Misreading the altitude is obviously an error and hence constitutes a design problem. Further details concerning the misreading of the flight altitude might be expected to inform a prescription, that is, a design solution. Altitude might be more clearly displayed, using colour or spatial coding.

In contrast, the implicit model of C^2 would appear to have little potential for informing research. Validation of design knowledge requires its conceptualisation, operationalisation, test and generalisation. Since the model is implicit, it is not (explicitly) conceptualised. Hence, it cannot be operationalised, tested or generalised, and so validated.

The explicit model of C^2 would also appear to have potential to support design. For example: "The **involvement** and **vulnerability** of the **neutral** and the **friend's power** with respect to it continue to increase rapidly". The greater involvement and vulnerability of a neutral is obviously an instance of ineffectiveness – hence a design problem – here resulting in "The **friend's power** with respect to the **neutral** is realised, with catastrophic results". The model also informs prescription, that is, a design solution, as it specifies the required domain state, that is, an 'uninvolved and non-vulnerable neutral'. Note the model does not inform design of the behaviours of the C^2 system itself, that is, how the neutral's uninvolvement and non-vulnerability might be brought about.

The explicit model would also appear to have the potential for informing research. As the C^2 concepts are explicit, it meets the requirement of research for conceptualisation. Since conceptualised, the model offers the potential for operationalisation, test and generalisation. Iran Flight 655 can be conceived and operationalised as a neutral, because its interest – civilian, commercial air transport – is compatible with both those of friends and enemies (see earlier). Once operationalised, the concepts can be tested and generalised. Note that the explicit model characterises C^2 as a class of domain, the Vincennes incident constituting an instance of the class.

Conclusion

This paper has assessed two contrasting approaches for their potential to model the domain of work for CE in support of design and research. It is concluded that both implicit, expert and explicit, research domain models have the potential to support design practice. However, the nature of the support is different. Implicit models support (re-) design of the instance, here embodied in the Vincennes incident, but not of the C^2 class (which remains implicit). In contrast, explicit domain models express the instance, embodied in the Vincennes incident, as a member of the C^2 class. Explicit model support for design is thus more general than implicit support. In contrast, explicit support is more limited, as it excludes the C^2 system itself. As concerns research, only explicit domain models have the potential to provide support, because implicit C^2 models cannot be validated in the absence of conceptualisation.

It is concluded, that implicit domain models of C^2 are needed, in the shorter term, to inform design of individual C^2 systems. Explicit modelling is currently in its infancy. However, explicit domain models offer the possibility of validation by research and so a better guarantee, in the longer term, of support for both design and research. The importance of explicit, domain models needs to be underlined and its further development encouraged. Only in this way can CE hope to progress from a craft to a more formal engineering discipline, so increasing the guarantee of its design knowledge.

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Appendix 1: An implicit, expert model (left column) and an explicit domain model (right column) of the Vincennes incident

0330 USS Montgomery reports that about seven Iranian small boats have challenged a tanker. Explosions are heard.	**0330** The **power** of the **enemy** (the small boats) with respect to the **resource** (tanker) increases. The **enemy** makes attempts to realise its **power**. The **security'** of the US **interest** is reduced.
0412 The Vincennes is ordered to the area to support Montgomery and investigate reports of small boats challenging a tanker.	**0412** The **friend's** (Vincennes') **power** and **involvement** increase, and the **vulnerability** of the **enemy** increases accordingly.
0610 The Vincennes' helicopter is diverted from a patrol to reconnoitre the small boats. By so doing, the helicopter and the small boats come within range of each other.	**0610** The **involvement, power** and **vulnerability** of the friend (Vincennes' helicopter) and the **enemy** increase rapidly.
0615 The helicopter is fired upon by the small boats, but no damage is inflicted. Having established the small boats' intentions, the helicopter returns to the Vincennes.	**0615** An attempt to realise the **friend's vulnerability** fails. Levels of **power, vulnerability** and **involvement** reduce.

0620 The small boats and the Vincennes continue to close.	**0620** The **involvement, power** and **vulnerability** of the **friend** (Vincennes) and the **enemy** increase again.
0643 The small boats and the Vincennes continue to close. Two small boats turn towards the Vincennes, while the other small boats manoeuvre erratically. (By so doing, the small boats have been drawn away from the tanker.)	**0643** The **involvement, power** and **vulnerability** of the **friend** and the **enemy** continue to rise. (The **friend's vulnerability**, however, is relatively low.) The US **interest** appears more secure.
0647 Flight 655 takes off from Bandar Abbas, and is detected by the Vincennes, as an 'unknown, presumed enemy'.	**0647** The **involvement** of the **neutral** (Flight 655) and the **friend** begins to increase.
0649 Flight 655 adopts its flight path, which is towards the Vincennes. The Vincennes challenges its air contact (actually Flight 655), but receives no reply. The period immediately after take-off is a busy time for flight crew, so they may not have been monitoring Air Distress frequencies. For a moment, Vincennes' air contact appears electronically to identify itself as a military aircraft (due to freak weather conditions?). Flight 655 is approaching the range of Vincennes' missiles.	**0649** The **involvement** and **vulnerability** of the **neutral**, and the **friend's power** with respect to it, increases rapidly.
0651 One of the Vincennes' guns jams when one of the small boats is about to adopt a dangerous position. A sharp change in course brings the remaining gun to bear on the small boat posing the greatest threat. Further challenges to the air contact receive no reply. Flight 655 is now within range of the Vincennes' missiles. Flight 655's altitude is mis-read. The air contact is perceived as diving towards the Vincennes; in fact, it is climbing away from it.	**0651** The **power** of the **friend** with respect to the **neutral** temporarily falls sharply, but is soon restored. The **vulnerability** of the **enemy** fluctuates accordingly. The **power** of one **enemy** also rises slightly before falling back. The **friend's vulnerability** fluctuates accordingly. The **involvement** and **vulnerability** of the **neutral** and the **friend's power** with respect to it continue to increase rapidly.
0654 Two surface to air missiles are launched by the Vincennes, in the belief that the ship is under attack from an enemy fighter. The missiles destroy Flight 655.	**0654** The **friend's power** with respect to the **neutral** is realised, with catastrophic results.
0703 The small boats leave the area. One has been destroyed and the Vincennes has incurred superficial damage from small arms fire or shrapnel. The Vincennes learns that is has mistakenly shot down a commercial aircraft.	**0703** The **power** of the **enemy** (with respect to the **friend**) reduces, as does the **involvement** of all parties. The **friend's power** with respect to the **enemy** has also been realised.