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Ethnographically informed analysis for software engineers

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It is increasingly recognized that human, social, and political factors have a significant impact on software systems design. To address this, ethnographic studies of work have been used to inform the systems design process, especially in cooperative work settings where systems support several users working together. Based on our experience of these studies, we have investigated the integration of social analysis into the systems design process by developing an integrated approach to social and object-oriented analysis. New methods are unlikely to be adopted in industry unless they can be integrated with existing practice. Our approach, called Coherence, addresses this issue by helping identify use cases, generating initial use case models, and by using the Unified Modelling Language (UML) to represent social aspects of work that may have an impact on the design of computer-based systems. Coherence is the fusion of two well-established strands of research on ethnographically informed design and viewpoint-oriented requirements engineering. This paper introduces Coherence, and focuses on the support provided for social analysis. We have identified three social viewpoints, namely a distributed coordination viewpoint, a plans and procedures viewpoint and an awareness of work viewpoint. Coherence is illustrated using a case study based on an air traffic control system.

1. Introduction

Existing methods to support computer systems design have mostly focused on the data to be processed by a system and the operations which process that data. Design methods do not address the problems of designing human interfaces, and they rarely acknowledge that computers are used by people working collaboratively in groups, not merely as individuals.

There have, of course, been techniques developed to address the lack of a human focus in systems development, coming out of work in the field of human–computer interaction (HCI). A good example of this is task analysis (Diaper, 1989; Johnson, 1992), which has been the subject of efforts to integrate with structured methods (Lim & Long, 1992; Lim, Long & Silcock, 1992). HCI techniques such as task analysis focus on the human interface issues for individual users of a system, but do not consider social and organizational factors. Research in computer-supported cooperative work (CSCW) has paid more attention to the social nature of work, and the impact it has on the systems introduced to support it. It is this tradition that is followed by the work reported here.

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Ethnographic studies have been widely reported in the CSCW literature (e.g. Harper, Lamming & Newmann, 1992; Heath & Luff, 1992; Heath, Jirotka, Luff & Hindmarsh, 1993; Bowers, O'Brien & Pycock, 1996). They provide useful insights into social aspects of work in situations where new systems are to be introduced. Our own experience of ethnography has involved working with sociologists on a number of projects, and in a variety of domains, including air traffic control (Bentley *et al*., 1992), system development (Rodden, King, Hughes & Sommerville, 1994) and banking (Blythin, Rouncefield & Hughes, 1997).

Whilst ethnography has demonstrated its usefulness in these studies, there are a number of problems with the technique as an approach to requirements elicitation that limit its chances of being adopted more widely in industry. These include issues of communicating the insights gained by ethnographers, either through their direct involvement in the design process, or via the medium of their written reports. The time taken to perform an ethnographic study can also be prohibitively long. It is therefore difficult to integrate it with the tight schedules of most system development processes.

To take advantage of the benefits of ethnography in systems design, there is a need for a systematic means of applying the lessons learned from ethnography, in a way that can be easily integrated with current working practices of software engineers. For such an approach to have the greatest chance of success the results of the analysis should be integrated with other computer system documentation, where they can be of most use for influencing and justifying design decisions. Furthermore, the approach should place as few extra demands on software developers as possible, in the form of new notations and processes.

In our current work, we have combined our experience of working with ethnographers with the development of viewpoint-oriented approaches to requirements engineering (RE), to produce a systematic approach for integrating social analysis with object-oriented analysis in computer systems design. Our concern with reducing the burden of learning "yet another method" on software engineers has led us to explore how our work can integrate with methods and notations established in industry. In particular, we have focused on the unified modelling language (UML) (Fowler & Scott, 1997; Rational, 1997) and use case-driven analysis (Jacobson, Christerson, Jonsson & Övergaard, 1992).

This paper presents our integrated approach, called Coherence, with a particular focus on the novel support provided for social analysis. In summary, we see the Coherence approach as a "front-end" method, which may be applied in conjunction with other analysis techniques. It supports the analysis of a problem situation and generates an incomplete set of inputs for more detailed object-oriented (OO) analysis. In essence, it addresses the key question in OO analysis—what are the essential use cases and associated objects? Figure 1 illustrates the Coherence approach, which has evolved from previous work on ethnographically informed RE (see Viller & Sommerville, 1999*b*) in that an ethnographer is not engaged in performing the fieldwork (but see below). Rather, the approach supports requirements engineers by focusing their attention onto pertinent social features of the domain under analysis. This in turn informs their development of requirements for the system being developed, including various models and other artefacts such as use case and object models. Coherence therefore becomes a part of the repertoire of techniques employed by requirements engineers, supplementing their existing approach to analysis with a technique that is particularly focused upon the social

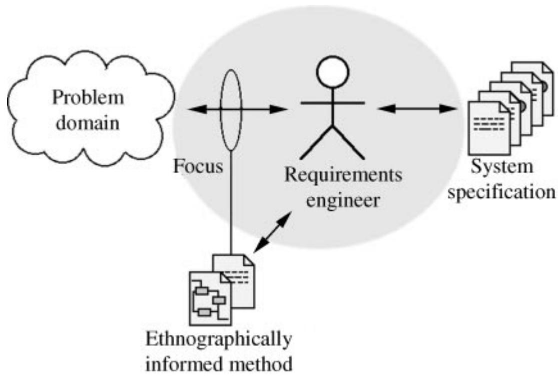

FIGURE 1. The Coherence approach focuses requirements engineers' analysis on social aspects of the problem domain and leads to the production of design artefacts.

aspects of the workplace. It is important to note, however, that whilst observational fieldwork may be engaged in when following Coherence, the approach should not be construed as "ethnography-lite", some cut down or simplified version of ethnography. Rather, the method is informed by cumulative experience of applying ethnographic approaches to the development of requirements for computer-based systems.

In fact, a side effect of the notational work in Coherence (Viller & Sommerville, 1999*a*) is that another possibility exists for how Coherence can be used. For organizations that already employ ethnographers to contribute to their RE processes, the guidance built into Coherence for generating use case and object models can be used by the ethnographers themselves. In this way, they can supplement how they report the results of their fieldwork to software engineers with models using an industry standard notation (UML) that communicate more directly to the design process. Nevertheless, the use for which Coherence was intended is to improve the understanding of social features of workplaces in requirements specifications produced as a result of the everyday work of software requirements engineers. To this end, it is the process embodied in the method that is just as important as the notation used. UML is designed to be used as part of a use case-driven analysis process, which draws heavily upon the work of Ivar Jacobson *et al.* (1992) on object-oriented software engineering (OOSE) which Coherence provides links to. The use of, and provision of links into, an industry standard notation and process is motivated by the desire to make Coherence useful to practising software engineers who will be more likely to use a technique if it integrates well with their existing methods and tools.

2. Background

This section presents the two main areas that underpin our work in developing a systematic approach to social analysis, namely ethnographically informed design and viewpoint-oriented requirements. Ethnographically informed design is the application of sociological approaches to systems development. Our previous work has culminated in various means of structuring the output from ethnographic studies to bring them closer to the design process. Viewpoint-oriented requirements approaches have developed out of concerns in the field of RE for the need to record and reason about requirements from more than one perspective.

2.1. ETHNOGRAPHICALLY INFORMED DESIGN

Descriptions of ethnographic studies of people using technology in cooperative settings are well established in the CSCW literature. Studies have been performed in a variety of settings, including air traffic control (Hughes, Randall & Shapiro, 1992; 1993*a*), stock exchange dealing rooms (Heath *et al*., 1993), doctors' surgeries (Heath & Luff, 1996), high street banks (Blythin *et al*., 1997), underground control rooms (Heath & Luff, 1992), print shops (Button & Sharrock, 1997), etc. The motivation for many of these studies was the interest of the ethnographers themselves in the work which they were studying, and the ways in which technology is used in collaborative ways in order to get the work done. All the studies can, however, be seen to be addressing issues and problems in the design of cooperative systems.

Ethnography is an approach to the study of work that is a highly distinctive branch of sociology (Button, 1991; Sharrock & Anderson, 1986). Ethnographic accounts are based upon detailed descriptions of human activity, resulting from prolonged periods as a "participant observer" in the work setting. In taking this approach, ethnography avoids the problems associated with the artificial nature of laboratory-based study, and produces accounts that are readily understood by the workers being studied. In particular, what ethnography offers the design process over other techniques is detailed accounts of how work is accomplished *in practice*, rather than how it may be specified, or how workers might report their actions in an interview.

The rise in popularity of ethnography as an approach to RE is relatively recent (Bannon *et al*., 1993; Goguen, 1993; Goguen & Linde, 1993; Jirotka & Goguen, 1994). Its popularity is largely due to the concerns within the field of CSCW for the social nature of work, and the need to understand it in order to develop support systems. The benefit that ethnographic studies have brought to the field of CSCW has largely taken the form of improved understanding of the way in which work is socially organized, and how seemingly mundane tasks can play a vital role in the successful accomplishment of the work.

A number of criticisms have been made of ethnography, however, concerning its use as a method of requirements elicitation (Hughes, O'Brien, Rodden, Rouncefield & Sommerville, 1995; Sommerville, Rodden, Sawyer, Bentley & Twidale, 1993). In essence, the criticisms aimed at ethnography as a method for RE are the following.

- Ethnography is typically a lengthy process, taking several months or even longer in some cases. RE simply cannot afford to make use of a technique that takes so long to produce results.
- Communicating the results of ethnographic studies to the design process is not straight-forward.

- Language and cultural barriers exist between sociologists and technologists.
- It is difficult to draw abstract lessons in the form of design principles from a technique that is concerned with the concrete detail of a particular situation.
- The success of an ethnographic study is dependent upon the skills of the individual fieldworker.

These criticisms are reflected in Ball and Ormerod's work (2000), which is concerned with developing an ethnographic approach that is better suited to design and that also gears into their theoretical perspective as cognitive psychologists. There have been a number of developments over the last decade that attempt to address these issues which restrict the perceived utility of ethnography as a method for RE. In particular, work in the COMIC project examined how the role of ethnography could be modified to make it more suitable for use in the design process (Bannon *et al*., 1993). This led to a number of different scenarios of ethnography in systems design (Hughes, King, Rodden & Andersen, 1994*a*), which are all aimed at integrating the process of ethnographic study into the systems design process. Contextual design (Beyer & Holtzblatt, 1998) was inspired by similar motivations, and is informed by ethnographic approaches, as well as other techniques from sociology, anthropology and psychology. A number of case studies also exist describing the use of fieldwork studies to inform design (Wixon & Ramey, 1996).

In a more theoretical consideration of the issues involved in using ethnography to inform design, Button and Dourish (1996) have described three different possible ways in which systems design might be influenced by ethnography. The direct involvement of ethnographers in the design process (as above) is the first, and the second is through accounts (i.e. written documentation) of the ethnographic study. This corresponds to more recent work that has examined how reports of ethnographic studies can be structured in terms of a number of dimensions of work (Hughes, O'Brien, Rodden & Rouncefield, 1977) (see also Section 3.1 for more details). The third option is by directly influencing the design process. This is the approach we are taking in the Coherence project where we have incorporated experience gained from performing ethnographic studies into a structured approach to requirements engineering.

2.2. VIEWPOINT-ORIENTED REQUIREMENTS ENGINEERING

The RE technique underlying our work is viewpoint-oriented requirements engineering, which we have used as a basis for structuring the social analysis by encapsulating the experience gained from using ethnography in systems design into three social viewpoints.

Viewpoints are used in Coherence as a means of structuring the information gained as a result of an ethnographically informed requirements elicitation process. The viewpoints referred to here result from work which culminated in the REAIMS project's PREview module (Sommerville & Sawyer, 1997; Sommerville, Sawyer & Viller, 1998).

In PREview, viewpoints are encapsulations of information about a system or process, i.e. about some aspect of the workplace under analysis. We are concerned here, however, with requirements viewpoints in particular for which each viewpoint is a partial analysis of the workplace, as seen from a particular perspective or focus. The complete analysis of the workplace is obtained through integrating and reconciling the multiple viewpoint analyses.

A viewpoint, as defined in PREview, consists of the following components.

- *Name*. An identifier, used to refer to the viewpoint, and usually chosen to reflect the focus of the viewpoint.
- *Focus*. A statement of the perspective adopted by the viewpoint.
- *Concerns*. The organizational goals and constraints that drive the analysis process.
- *Sources*. The sources of information associated with the viewpoint. The sources may be people, documents, requirements, other viewpoints and so on.
- *Analysis* (*requirements/model description*).† The analysis of the system or process as seen from the focus of the viewpoint.

The main feature that distinguishes PREview from other viewpoint approaches is its use of *concerns* to drive the analysis. Concerns directly reflect the goals of the organization and global requirements that must be satisfied. They must therefore be taken into account in all other aspects of the analysis. It is this global feature of concerns which distinguishes them from viewpoints, and leads to the two concepts being treated as orthogonal, as illustrated in Figure 2.

Concerns shift the perspective of PREview from what the system should do, to how it can best serve the organization. They explicitly link organizational goals and objectives with system requirements. The treatment of concerns starts at an abstract level, and they may include safety, maintainability, compatibility and even the functionality of the system. They are elaborated into *questions*, which must be asked of every viewpoint source to collect information about the system and/or *external requirements*, which are applied across all viewpoints to ensure that they comply with the organizational concerns.

This structure of viewpoints and concerns is adopted in Coherence, although some of the analysis is simplified due to the focus on the social aspects of the system. Coherence initially deals with three social viewpoints, namely: *distributed coordination*; *plans and procedures*; and *awareness of work*. These viewpoints directly correspond to the social dimensions of work in the CSCW presentation framework developed by sociologists at Lancaster (Hughes *et al*., 1997). They have been arrived at as a result of cumulative experiences of performing ethnographic studies in a variety of situations. Similarly, a number of concerns are also built into Coherence's viewpoints framework, namely: *paperwork and computer work*; *skill and the use of local knowledge*; *spatial and temporal organization*; and *organizational memory*. In the CSCW presentation framework, these appeared as "issues arising out of the fieldwork" which cut across the three dimensions of work. Thus, the structure of viewpoints with orthogonal concerns mirrors the structure of dimensions and issues in the presentation framework. Coherence takes advantage of this correspondence, and presents the dimensions as *social viewpoints*, and the issues as *social concerns*.

† PREview actually consists of two viewpoint-oriented approaches. One for requirements engineering, and another for process improvement. Hence, the analysis part of a viewpoint record may contain either system requirements, or one or more models of the process to be improved, from that viewpoint.

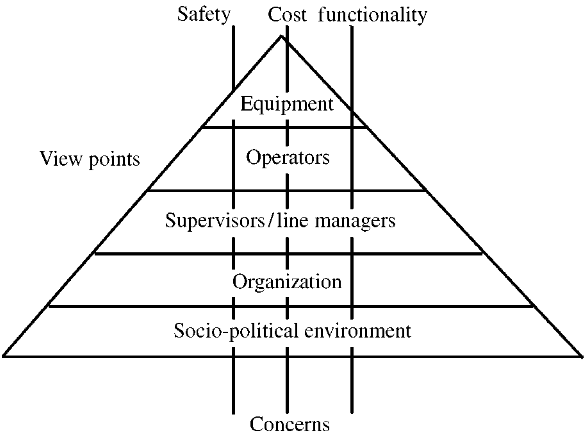

FIGURE 2. The orthogonality of viewpoints and concerns (from Sommerville *et al.*, 1998).

3. Structuring the social analysis

Coherence can be seen as introducing a number of viewpoints and concerns to PREview analysis, all of which are informed from a social perspective. In this way, the social viewpoints and concerns are considered alongside the viewpoints and concerns that are identified from the problem domain. This not only structures the analysis of social issues, but also integrates social analysis with a multi-perspective approach to requirements engineering.

However, we must emphasize here that Coherence is not dependent on PREview and the social viewpoints may be used on their own to support the social analysis of work settings. Therefore, our method may be used as a simple approach to social analysis in conjunction with any other analysis method.

3.1. SOCIAL VIEWPOINTS

In Coherence, we advocate focusing on three social viewpoints, namely: *distributed coordination*; *plans and procedures*; and *awareness of work*. We have chosen these viewpoints as a result of our experience of a number of ethnographic studies. They have previously been incorporated as dimensions in a framework for the presentation of ethnographic studies in the design process (Hughes *et al.*, 1997).

The social viewpoints should not be considered as orthogonal dimensions for understanding the workplace. Just as for any other set of viewpoints, they are all interrelated with several overlaps between them. Rather, each social viewpoint provides a different emphasis when considering the social aspects of the workplace and the work being performed. Different viewpoints have different foci, which in turn lead the analyst to attend to different aspects of the workplace. The focus of each social viewpoint concentrates on one perspective of the social organization of the workplace and the work as it is performed. Elaboration of each social viewpoint is assisted by a number of questions that direct the analyst to features of the workplace that are relevant for understanding the work from the given perspective. These focus questions are intended to sensitize the analyst to workplace features that are pertinent to the particular social viewpoint or concern. The examples provided in the following sections should not be considered as exhaustive lists. Rather, they should be seen as a starting point which can be expanded upon or specialized in the light of experience in a particular domain, or as a result of applying Coherence in general.

3.1.1. Distributed coordination

Distributed coordination is used to refer to the ways in which coordination of people and tasks is achieved as a part of everyday work. Work tasks are performed as a part of patterns of activity, operations within the context of a division of labour, contributions towards ongoing work processes, etc. Each activity is dependent upon other activities, and work is oriented towards others in the workplace who will make use of it. Many tasks are performed in order to enable others to get their work done, or are steps in a sequence of tasks where the other steps are performed by other people. Similarly, individuals in the workplace develop an idea of what is their responsibility, and what is "someone else's".

In terms of systems development, focusing on distributed coordination issues in the workplace should lead to better informed support for action and tasks in the system, especially where artefacts are worked on by more than one person. Table 1 presents questions used to help focus the analysis on workplace features that are related to distributed coordination.

3.1.2. Plans and procedures

Plans and procedures refer to the different objects that are generated in a workplace to document the step-by-step process for completing the various tasks that together make up the work. They are a prominent means by which distributed coordination is practically achieved in an organization. It is important to build up a clear understanding of how plans and procedures are used to organize activities. Consequently, consideration of this viewpoint should identify the different participants in the process and their relationship to plans and procedures, be sensitive to and record different viewpoints on plans and procedures and also to different notions of "following a plan". Also of importance here is the ways in which work deviates from the documented procedures. Such deviations may

TABLE 1
Focus questions for distributed coordination viewpoint

How is the division of labour manifest through the work of individuals and its coordination with others?
How clear are the boundaries between one person's responsibilities and another's?
What appreciation do people have of the work/tasks/roles of others?
How is the work of individuals oriented towards others?

TABLE 2
Focus question for plans and procedures viewpoint

How do plans and procedures function in the workplace?
Do they always work?
How do they fail?
What happens when they fail?
How, and in what situations, are they circumvented?

be indicative of documentation simply not being up to date, but it may also point to different approaches to carrying out the work that are due to other reasons such as local problems that have emerged which must be worked around.

Artifacts such as project plans and schedules, manuals of instruction and procedures, job descriptions, formal organizational charts and workflow diagrams are all examples of plans and procedures. Questions to help focus analysis on plans and procedures are presented in Table 2.

3.1.3. Awareness of work

Awareness of work refers to the way in which activities are organized in order to make them "visible" or "intelligible" to others doing the work. Workplaces have physical layouts which can affect (either facilitate or inhibit) the ability of people to make reciprocal sense of the others' activities. This visibility or intelligibility may take place through talking aloud as one works, or through representations of the work to be done (forms, worksheets, etc.) which make obvious the current stage of the work.

One particular feature this viewpoint is concerned with is the spatial organization of the work setting, and the impact this has on how work is achieved. The layout of the workplace reflects and has an impact on the division of labour, the allocation of roles between individual workers and the processes followed.

The primary aim of this viewpoint is, therefore, to gain an understanding of the physical layout of the workplace, how people in the workplace organize their personal space to support their work, how individuals monitor the work of others and make their own work available for such monitoring by others. Assistance for focusing analysis on these and other workplace features related to the awareness of work are presented in Table 3.

3.2. SOCIAL CONCERNS

This section introduces the major concerns that have arisen out of previous experience of using ethnography in systems design (Hughes *et al*., 1995, 1997). These concerns each have an impact on the above social viewpoints. Concerns are used during the analysis by identifying a set of questions associated with each concern and asking these questions to

TABLE 3
Focus questions for awareness of work viewpoint

How does the spatial organization of the workplace facilitate interaction between workers and with the objects they use?
How do workers organize the space around them? Which artefacts that are kept "to hand" are likely to be important to the achievement of everyday work?
What are the notes and lists that the workers regularly refer to?
What are the location(s) of objects, who uses them, how often?

the information sources in each viewpoint. This ensures coverage of what we have found to be key issues in social analysis.

Not all of these concerns are necessarily relevant for every workplace studied, and so these should be regarded as a starting point for the social concerns which *may* be relevant. Coherence analysis first of all determines whether all of the following concerns should be elaborated for a given context. In the light of workplace observation, other concerns may well emerge that should also be considered alongside each of the viewpoints. Similar to the social viewpoint elaboration, a number of questions are provided to assist in the elaboration of the social concerns in the situation being studied. These questions also serve as a means for making judgements on the relevance of the concerns in the current context.

3.2.1. Paperwork and computer work

This concern refers to the way in which existing paper and computer-based systems function, and how they are utilized by people in the workplace. As enablers of distributed coordination and mechanisms of articulation for distributed coordination, paperwork and computer work are also a major embodiment of organizational plans and procedures, and a mechanism for developing and sharing the awareness of work. As such, there are a number of questions to consider when thinking about how paper and technology are used in the workplace. Table 4 presents questions for focusing the analyst on issues relating to this concern.

TABLE 4
Focus questions for paperwork and computer work concern

How do forms and other artefacts on paper or screen act as embodiments of the process?
To what extent do the paper and computer work make it clear to others what stage people are at in their work?
How flexible is the technology at supporting the work process—is a particular process enforced, or are alternative permitted?

3.2.2. Skill and the use of local knowledge

Despite frequent attempts to "de-skill" the work of individuals by reducing it to rules, laws and procedures, considerable skill is still required to know when one particular plan may fail, when to take a particular shortcut and so on. This concern relates to how workers apply their skills in order to successfully perform their tasks and how they access and make use of "local knowledge", which refers to the workarounds and shortcuts that evolve over time to make the job easier. Local knowledge is often made use of by asking a neighbour for help, rather than turning to official procedures. Questions to assist in focusing the analysis on these issues are presented in Table 5.

3.2.3. Spatial and temporal organization

The way in which work is organized in physical space and across time can create both problems and possibilities for distributed coordination, and the awareness of work. This makes the development of organizational plans and procedures essential for the successful accomplishment of the work. This concern focuses the analysis upon the relationship between the spatial layout of the workplace and the work performed in it. Attention is also drawn to temporal aspects of the work, and how people perform their work in situations where time is an issue. Table 6 presents a number of questions to focus analysis on this concern.

3.2.4. Organizational memory

Whilst plans and procedures are formally recorded in action sheets, instruction manuals, etc., there are frequently other ways in which the plans are "remembered" in practice (Randall, O'Brien, Rouncefield & Hughes, 1996). For example, a local expert may be

TABLE 5
Focus questions for skill and the use of local knowledge concern

What are the everyday skills employed by individuals and teams in order to get the work done?
How is local knowledge used and made available, e.g. through the use of personalized checklists, asking experts, etc.?
To what extent have standard procedures been adapted to take local factors into account?

TABLE 6
Focus questions for spatial and temporal organization concern

How does the spatial organization of the workplace reflect how the work is performed?
Which aspects of the work to be supported are time-dependent?
Does any data have a "use-by-date"?
How do workers make sure that they make use of the most up-to-date information?

TABLE 7
Focus questions for oganizational memory concern

How do people learn and remember how to perform their work?
How well do formal records match the reality of how work is done?

turned to, or workers may keep their own "crib sheets" and checklists for what to do in particular situations. Table 7 presents questions to assist in elaborating this concern.

The context of the design brief, feasibility study, etc., will usually provide other concerns which should be addressed, such as safe operations, etc. Concerns such as this are elaborated in the PREview process, which identifies and elaborates viewpoints in the domain, and generates associated requirements.

4. Linking with system models

One of the main goals of this work was to produce an approach that fits well with standard methods already in use. Our initial choice has been to link Coherence analysis with the use case-driven approach as originally specified by Jacobson *et al.* (1992). Interest in the use of approaches based on use cases and scenarios (Carroll, 1995) has grown significantly in recent times. A further advantage of linking with use cases is that, whilst they have evolved out of research into object-oriented development, it is possible to use them with other approaches based around functions or processes.

Nevertheless, it is object-oriented analysis that has been chosen as the primary target for Coherence. In addition to linking through to use case models, Coherence also makes use of UML (Fowler & Scott, 1997; Rational, 1997) as the notation for expressing social aspects of the workplace. We have already shown that it is possible to make use of the extension mechanisms that are built into UML in order to express social features of workplaces (Viller & Sommerville, 1999*a*) but this is not the focus of this paper. Here we concentrate on how Coherence can be used as a route into object-oriented analysis via use case models.

Jacobson *et al.* (1992) use the term requirements model to describe the model of the current system (differentiated from the analysis model, which specifies a system to address the problem as specified in the requirements model). The requirements model consists of the following three components.

- The *use case model* which drives the whole development process, and describes the interaction between users (actors) and the system.
- *Interface descriptions*, which describe the means by which actors communicate with the system (e.g. human interface prototype, communication protocols, etc.).
- The *problem domain object model*, which contains the specification of (logical) objects with direct (physical) counterparts in the work space or problem domain.

The remainder of this section describes, for each concept in the OOSE requirements model, how Coherence builds up relevant information from study and analysis of the workplace. It should be noted that the following concepts, whilst components of the

OOSE requirements model, can all be modelled using UML's notation. In fact, one of the first uses of UML's extension mechanisms was to define the special types of object defined in OOSE.

4.1.1. Actor

According to Jacobson *et al.* (1992), an actor is an external interactor with the system. This corresponds directly to *interactor viewpoints* as specified in PREview, and used in Coherence. Interactors are defined as:

> ⋯ something (human or machine) which interacts directly with the system being specified. Examples include human operators who impose usability requirements or requirements for specific process support functions and external systems which impose compatibility and information exchange requirements. (Sommerville & Sawyer, 1997, p. 113).

Interactors are identified and then used to generate viewpoints. There will therefore be a number of viewpoints in Coherence that can be directly modelled as actors in use case diagrams.

4.1.2. Use case

Each use case for a particular system describes a meaningful interaction between an actor and the system. Use cases are described as a number of scenarios, which detail a particular course of interaction (different scenarios covering different courses of events, exceptional circumstances, etc.). The plans and procedures viewpoint in particular is concerned with describing such flows of work, and naturally leads to a number of descriptions of procedures as observed. These correspond quite closely to (but are not necessarily coincident with) use case descriptions.

4.1.3. Problem domain object model

The problem domain object model is concerned in particular with modelling real-world objects, rather than objects that are abstract or specific to the implementation of the system. The distributed coordination and awareness of work viewpoints both identify a number of objects in the domain that play a role in coordinating the work between the actors in the domain.

4.1.4. Object model

Coherence does not lead directly to a complete object model of the system. It will, nevertheless, produce a number of excerpts from the model, particularly resulting from the awareness of work viewpoint, which describes relationships between problem domain objects that have an impact on awareness.

4.1.5. Interface descriptions

Coherence is not directly concerned with interface design issues. This is not to say, however, that potential designs and prototypes for system interfaces will not arise in the course of Coherence analysis. It is important that any such designs or prototypes are recorded so that they can influence subsequent designs based upon the requirements produced by Coherence.

TABLE 8
Summary of links from Coherence to use case models

Actor	Interactor stakeholders are identified and then used to generate viewpoints
Use case	Use case descriptions are generated by plans & procedures viewpoint
Problem-domain object model	Problem-domain objects are identified by distributed coordination and awareness of work viewpoints
Object model	Fragments of model generated by awareness of work viewpoint
Interface descriptions	Not directly addressed by Coherence, but can be recorded in UML models

Table 8 summarizes the correspondences between the main components of the Jacobson *et al.* requirements model, and components in the Coherence approach.

5. Application to air traffic control

This example is based on a study of London Air Traffic Control Centre (LATCC) previously conducted by sociologists and computer scientists at Lancaster University (Sommerville, Rodden, Sawyer & Bentley, 1992; Hughes, Sommerville, Bentley & Randall, 1993*b*). The following sections return to the study in order to present an application of Coherence, based on the fieldwork done at the time. We have done this to illustrate how Coherence can be used as it was intended, but without the need to gain access to an organization for conducting fieldwork, with the increased cost and complexities involved. The data from the original ethnographic study were used here to provide a level of contextual information not available to someone who was not directly involved in the original fieldwork.

5.1. THE LONDON AIR TRAFFIC CONTROL CENTRE

The London Air Traffic Control Centre (LATCC) at West Drayton is responsible for controlling all flights in U.K. airspace. The control room consists of eight control suites, each one dealing with two sectors of airspace: that is, blocks of airspace defined laterally and vertically and layered into flight levels (see Figure 3). The airspace of England and Wales is divided into 16 sectors. As an aircraft flies through controlled airspace along static routes it is passed from sector to sector under the direction of Air Traffic Control Officers (ATCOs) whose main task is to ensure the safe separation of aircraft as well as the expeditious flow of traffic.

The controlling team around a suite responsible for a sector normally consists of the radar controller for a sector, a “wingman”, or assistant controller, and a Chief. The active controller is responsible for the moment-to-moment control of aircraft. The assistant controller is generally responsible for collecting and checking paper flight strips as they

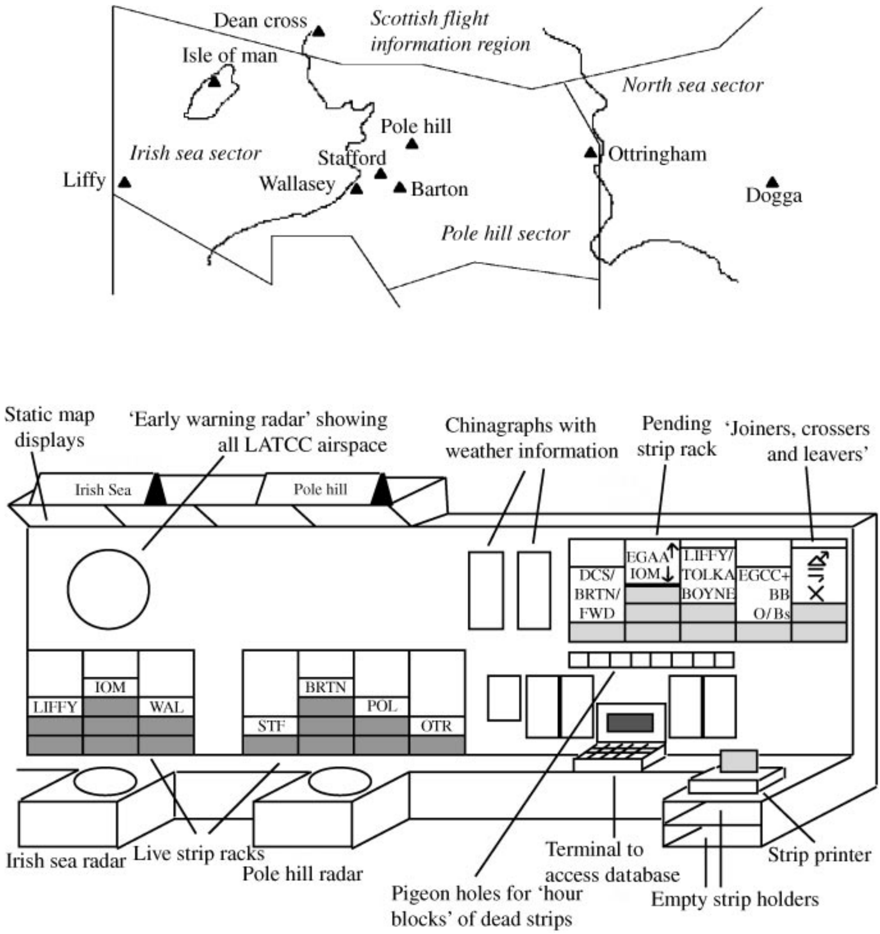

FIGURE 3. Simplified arrangement of Pole Hill Suite and Map of Pole Hill Sector[2] (from Hughes, Sharrock, Rodden, O'Brien, Rouncefield & Calvey, 1994*b*). The figure is simplified and not to scale. The map is included to show how the physical layout of suites and the order of the racks containing flight strips correspond to the geographical locations they represent. ■ Live flight strip; □ Pending flight strip

are produced from the printer, and occasionally liasing with adjacent sectors. The Chief is responsible for non-standard flights and generally overseeing the suite.

Radar controllers have three main tools to support them. The radar display shows a trail of blips representing a particular flight, with a data block alongside showing flight number and flight level. RT links allow controllers to talk to pilots, radar controllers on other suites and to neighbouring airspace. Paper flight progress strips contain more detailed information about particular flights. These are printed from a database of filed flight plans.

For the purposes of explaining the Coherence approach, the remainder of this section highlights the results of applying Coherence to the analysis of a system to automate the paper flight strips, which are central to the task of controlling the airspace. Whilst the results are presented in a sequential, waterfall-like manner, it should be noted that the Coherence process is iterative. Requirements are not only generated at the end, but will emerge at various points in the process. Similarly, the status of concerns and viewpoints is not static, with the possibility of some viewpoints evolving into concerns in the light of analysis, or concerns into viewpoints.

5.2. INCORPORATING SOCIAL CONCERNS

PREview begins with the identification and elaboration of concerns, which represent organizational goals for the system under development. For LATCC, safety is an obvious concern. Elaboration of the safety concern takes the form of a hazard analysis for the system, leading to a number of external requirements that the system should satisfy. These external requirements typically take the form of identifying the hazardous conditions that the system must detect and/or avoid, such as poor separation of aircraft, or instructions to aircraft that could lead to a collision. Another concern for LATCC would be to increase the volume of air traffic that can be handled without compromising safety.

Coherence, however, is interested in the social concerns already identified in Section 3. These concerns must be further elaborated in the light of detailed information gained from analysis of the workplace. It is not necessarily the case that all of the viewpoints will apply to every given situation. For this reason, the first task to perform is to ascertain the applicability of the social concerns. To do this, concerns are adjudged to be highly relevant, not relevant or neutral in the current context. This is achieved with reference to the social concern questions, recasting them to ask whether certain social features exist in the workplace, rather than how are they manifest. For example, "Do forms and other artefacts on paper or screen act as embodiments of the process?" or "Is local knowledge used and made available?"

If most or all of the concern questions have positive responses, then the concern is highly relevant. Depending upon how many negative responses exist, the concern may be neutral or not relevant. Concerns deemed to be not relevant may be omitted from the remainder of the analysis. In the ATC example, all the concerns are relevant with the exception of organizational memory, which is neutral. This means that it is not discarded at this stage, but is marked for possible removal later in the process.

The elaboration of social concerns in Coherence gives rise to a number of descriptions of the workplace as prompted by the concern questions. For example, the paperwork and computer work concern gives rise to the descriptions provided in Table 9. The first section of the table describes features of the workplace, in response to the questions for that concern. External requirements and questions arising from the description are entered in the next two sections, respectively.

Once external requirements and/or questions have been identified for each of the social concerns, they can be treated in the same way as the organizational concerns for the remainder of the requirements process.

With the concerns elaborated, the focus of the analysis switches to viewpoints, their identification and elaboration. The identification of viewpoints is one of the links to use case analysis mentioned earlier, and it therefore merits attention now.

TABLE 9

Elaboration of paperwork and computer work concern. External requirements (ER1–ER3) emerge from the analysis of the workplace as prompted by the concern's focus questions

Paperwork and computer work The main feature of a control suite that this concern is interested in is the flight strip itself. As a consequence, the following concern questions responses all focus on how the flight strip is used by ATCOs in the course of their work. Flight strips embody the process of an aircraft's progress through the sector of airspace controlled by a suite. As an aircraft approaches the sector, its strip is moved progressively to the bottom of the rack until it becomes the current strip for the controller to deal with. The work of the controller can therefore be viewed in terms of dealing with the flow of strips as aircraft enter, traverse and leave the controller's sector. The collection of strips in various racks in a suite provide an "at a glance" means of determining the current and future workload of a particular controller. The practice of 'cocking out' strips—raising them slightly in the racks—informs the controller that there is something non-standard about the flight concerned. This may be done by the assistant controller when inserting the strip, or by the controller as a reminder. Glancing at the strips provides a controller with an indication of their current and future workload, in the same way as it allows other controllers to see the relative loading on other sectors. This feature of the organization of the strips is used in particular at change over of shifts, where the incoming controller will spend up to 10 min looking over the shoulder of the out-going controller in order to "get the picture" of the current state of the sector. Flight strips provide incredibly flexible support for the work of controllers. Different practices exist regarding whether strips are placed into the racks in a top to bottom sequence or vice versa. All instructions given by controllers to pilots, and the pilots' acknowledgements, are recorded onto the relevant flight strip. These annotations are made using a standard set of symbols, and different coloured pens according to the annotator's role within the controlling team. In this way, flight strips constitute a record of a flight's progress through a sector.
ER1. The system shall support controllers "getting the picture" by providing the ability to determine current and future load for a sector "at a glance" ER2. The system shall provide a facility to mark exceptional or non-standard flights requiring special attention ER3. Annotations to flight records shall be recorded and presented in such a way that they identify the person who made them.
No questions for this concern.

5.3. IDENTIFYING VIEWPOINTS

We support viewpoint identification with a generic viewpoint hierarchy, which classifies viewpoints into three main classes, namely: interactor; stakeholder; and domain phenomenon. The hierarchy can be tailored to a particular organization or application domain, and provides the analyst with a framework for examining the workplace for viewpoint candidates. Of particular interest here is the interactor class of viewpoint, which was defined above. This branch of the viewpoint classification is presented in Figure 4.

It can be seen from this that under the operator node, an *ATCO* viewpoint has been added, which in turn can be broken down into *Chief*, *Assistant* and *Active* controllers. The further breakdown is necessary because of the different roles played by controllers in

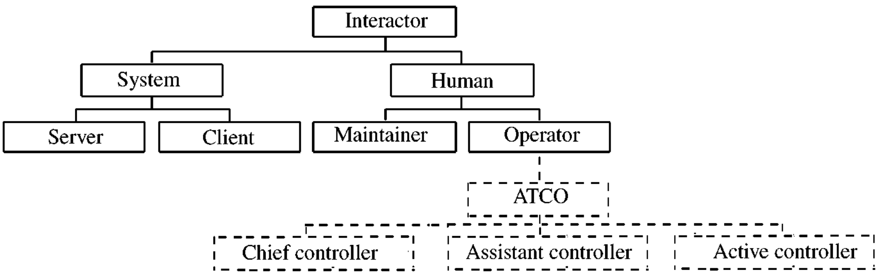

FIGURE 4. Interactor viewpoint hierarchy.

the different jobs. The leaf nodes on this branch of the viewpoint hierarchy correspond directly to actors in the use cases for the system.

The stakeholder branch of the viewpoint hierarchy leads to the identification of viewpoints corresponding to people, organizations, external sources of information or regulation, etc., that have no direct interaction with the system, but nevertheless have a stake in its output. Of particular note here for the ATC example is the *Manual of Air Traffic Control*. This is the set of rules that the ATCOs must apply while performing their duties, and acts as a resource of requirements that the system must comply with. Documented rules and plans are particularly of interest to the social viewpoints, which is where we turn to next.

5.4. ELABORATING SOCIAL VIEWPOINTS

The three social viewpoints must now be elaborated. Each viewpoint will generate a set of requirements for the system, from a particular perspective. Table 10 presents the awareness of work viewpoint, for example. Here, the generic focus given earlier in Section 3.1.3 has been re-stated in the context of the current application to ATC. The list of concerns may be pruned if any are deemed not to apply to the viewpoint, as is the case for organizational memory. The external requirements and questions in the remaining concerns must all be checked against the requirements in the viewpoint. The requirements are merely listed in the viewpoint record, and are elaborated in more detail elsewhere. The three requirements listed in this example are concerned with the need for the system to (1) provide support for controllers to make their work available for scrutiny by others (AWI): (2) provide information on controllers work so that it may be scrutinised (AW2); and (3) pay attention to how the physical layout of the control suites maps onto the physical layout of the airspace being controlled (AW3).

In a similar way to the social concerns, once the social viewpoints have been elaborated this far, they can be treated exactly as the other viewpoints in the PREview analysis. This is one mechanism by which the social analysis is fed into the more mainstream requirements process.

5.5. IDENTIFYING AND GENERATING INITIAL USE CASES

So far, this case study has been largely concerned with how the social concerns and viewpoints in Coherence are elaborated. We now turn to how Coherence provides

TABLE 10

Awareness of work viewpoint. The three requirements (AW1–AW3) are elaborated separately using PREview requirements record tables

Name:	Awareness of work
Focus:	How the physical organization of the control suites affects how controllers can make sense of each other's activities. How controllers monitor the work of other controllers, and how controllers orient their work to facilitate others monitoring it.
Concerns:	Paperwork and computer work Skill & the use of local knowledge Spatial and temporal organization ~~Organizational memory~~ Safety Volume of traffice
Sources:	Controllers, and observation of controllers at work
Requirements:	AW1 (Making work available) AW2 (Availability of awareness information) AW3 (Relationship of suite layout to controlled airspace)

a route from these initial stages of requirements analysis to use case models, and on to object models.

Of particular importance here is the plans & procedures viewpoint, which focuses our analysis on workflow. Because Coherence has its roots in ethnography, it is concerned with how work is carried out in practice, rather than how it is documented. As a consequence, it is also concerned with how practice differs from documented procedures. One interesting feature of the work of ATCOs is how they will occasionally deliberately place aircraft on conflicting paths in order to be able to deal with a problem elsewhere, in full knowledge that they will have to return to the first problem a short while later. This is an example of how rules can be broken "locally" in order for the overall spirit of the rules to be followed. Coherence is particularly interested in such a phenomena, because if the system were to rigidly enforce the rules as set out in the manual, this type of behaviour would not be possible.

The plans and procedures viewpoint, therefore, is concerned with describing how the work (of controllers in this case) is carried out in practice, and how and on what occasions this differs from documented procedures. This focus on the activity of people in the workplace in terms of what is routine activity, what exceptions occur and how they differ from the routine, leads naturally to a description of the work as use cases. In combination with the actors identified in the process of identifying viewpoints, there exists a straight-forward route from Coherence to use case models. A simple initial use case model for the ATC example is presented in Figure 5.

This model illustrates the responsibilities of the three types of controller who work a suite. The active controller handles all the standard flights through the sector, while the chief controller takes care of non-standard flights. The assistant controller is responsible

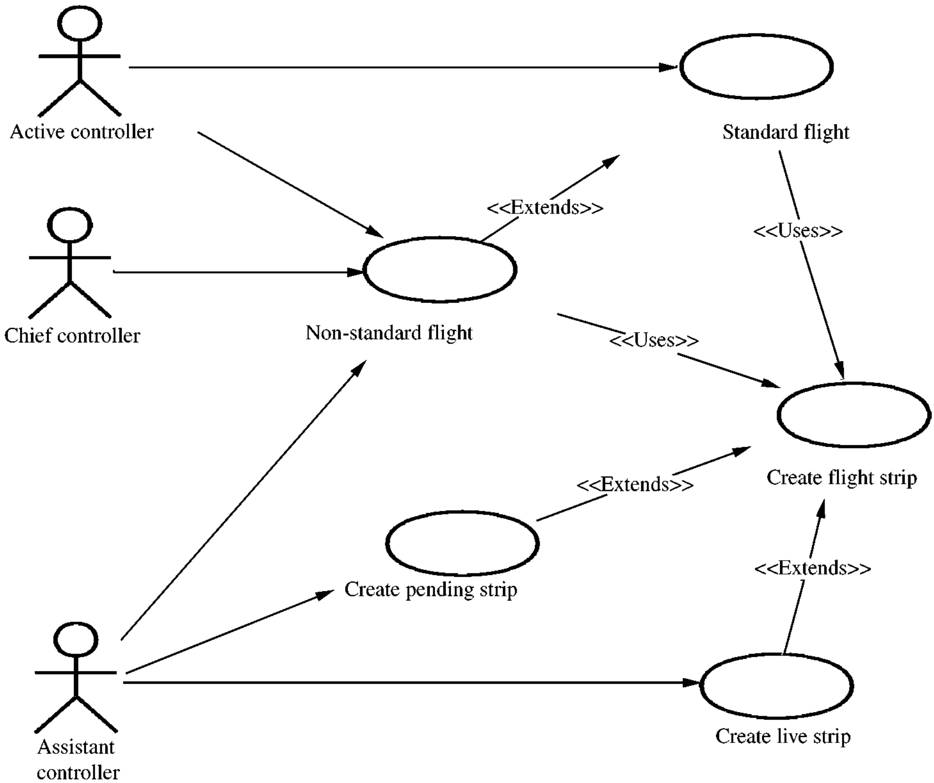

FIGURE 5. Initial use case model for ATC example.

for generating the flight strips, placing them in the relevant rack and "cocking them out" (marking as non-standard) for the exceptional or unusual flights. Pending strips and live strips perform different functions, and display different information. Pending strips are used mainly to display information regarding flights that will be entering a particular sector in the future, and are generated on filed flight plans. Live strips are created nearer to the time that a flight enters a sector, and are updated by the assistant controller to contain the latest information regarding the flight's heading, flight level and so on. The use cases are generated in the light of observed workplace interaction, and reflect the actual tasks engaged by ATCOs in the course of controlling a sector of airspace. The main two use cases in this diagram are `create flight strip` and `standard flight`. They are both invoked for every flight that passes through the given sector. `Standard flight` is the use case which describes the routine activity of ATCOs controlling flights passing through their sector where the aircraft are following pre-filed flight plans. Deviations from these standard routes require interaction between ATCO and pilot, and this is known as *coordination* (see Section 5.6.1). Coordination is represented as a sub-use case within the `standard flight` use case.

5.6. REPRESENTING SOCIAL ASPECTS IN UML

The final component of Coherence's approach to making social analysis accessible to software engineers is the use of standard notations for describing the social features of the workplace. Two standard modelling forms in UML are utilized, namely sequence diagrams, and class diagrams. The former are used to represent sequences of interaction in the workplace, between actors and objects within the system. The latter are used to model structural aspects of the workplace, such as objects that are manipulated by the actors, and relationships between them. There is no set order in which these two types of model should be created, but producing sequence diagrams naturally leads to the identification of instances of objects that will subsequently be modelled in class diagrams.

5.6.1. Modelling sequences of workplace interaction

Sequence diagrams present a flow of messages passed between an actor and objects in the system or workplace in the course of following a use case. Each sequence diagram used in this manner describes a scenario, and all the scenarios together go to make up the description of the use case as a whole.

Coherence uses sequence diagrams in two ways. First, Coherence can be used as a means of presenting ethnographic workplace studies in a standard notation (Viller & Sommerville, 1999*a*). Figure 6 is an example of a sequence diagram, used to represent an extract from the fieldnotes for the ATC study. In this example, a controller contacts the pilot of "Speedbird 799L" and requests them to alter their flight level. The pilot acknowledges the instruction, and finally the controller records the change on the corresponding flight strip. This is an example of the sequence of interaction referred to above as coordination. The act of coordinating a flight refers to any case where an

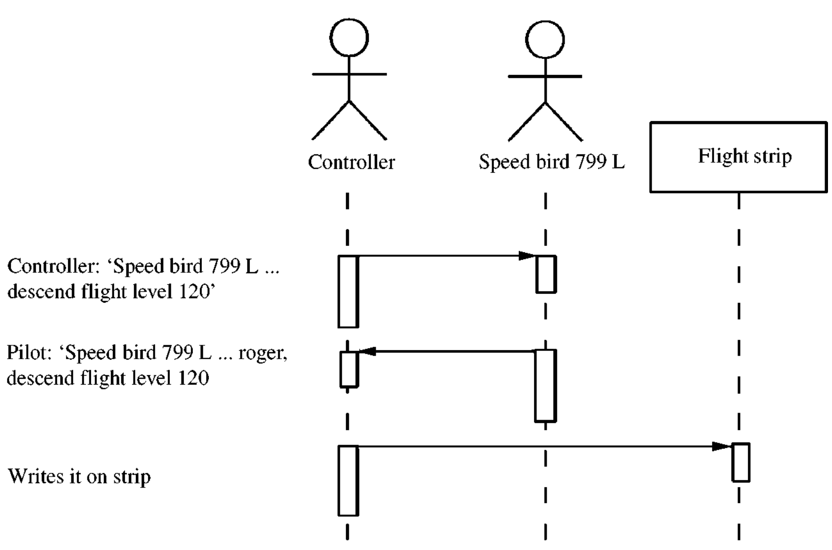

FIGURE 6. A transcript of observed interaction represented as a sequence diagram.

aircraft deviates from the standard, pre-filed, flight plan for the route that it is following. A flight may require coordination for a number of reasons, such as busy periods of traffic causing congestion in certain sectors, pilots wishing to avoid turbulence at a particular flight level or non-standard flights on conflicting headings. The fact that coordination entails that the flight is no longer following its standard route, as filed prior to take-off, does not mean that the `Standard flight` use case is no longer being followed. Coordination of flights is such a common occurrence that it too is considered to be part of the activity of controlling a standard flight.

The second use of sequence diagrams in Coherence moves away from direct representation of sequences of observed interaction, towards abstractions of the activity, which is a step closer to describing the workplace from the perspective of the system being developed. Where detailed records of interaction are available, as is the case for ethnographic fieldnotes, there is a tension here between producing abstractions that are useful contributions towards the design of a system, and maintaining the detailed information about the domain that are available in the fieldnotes. The more frequent and routine an activity, the easier this task becomes. In the ATC study, despite there being subtle differences between almost every instance of coordination in the notes, a pattern nevertheless emerges of a sequence of interaction involving communication between controller and pilot, acknowledgement of the resultant action by the pilot and recording of this on the relevant flight strip. This can be represented in a sequence diagram as in Figure 7. Different diagrams can be similarly developed for alternative sequences for coordination, such as when a pilot initiates the sequence, or when the controller from a different suite coordinates a flight which is about to pass from one sector to another. Each of these alternative courses of interaction *extend* the standard use case for coordination (see Jacobson *et al.* (1992) for explanation of use case modelling constructs such as ≪extends≫ and ≪uses≫ relationships).

5.6.2. Modelling objects in the workplace

The act of modelling interaction with the system in the above manner leads the analyst to create objects that describe parts of the system (the `Flightstrip` object being the obvious example from the previous section). Social viewpoints, such as awareness of work and distributed coordination, will already have identified some of these objects in the course of their analysis. Together, these objects can be added to the domain object model.

Returning to the use case model presented in Figure 5, our analysis from the Plans and Procedures viewpoint led to the identification of two alternatives for the `Create flight strip` use case. The structure of this part of the use case model naturally leads us to consideration of a class hierarchy for objects of type `Flightstrip`. The different types of strip implied by the use cases exist for different purposes in an ATC suite. Pending strips are usually printed approximately two hours before an aircraft is due to arrive in a sector, whereas live strips are printed closer to 40 minutes prior to the flight's arrival. The extra time that they exist for before a flight enters controlled airspace offers a number of affordances (Anderson & Sharrock, 1993) for pending strips.

- They can serve as an advanced warning of build-up of traffic about to enter the sector.
- They indicate input errors in the flight plan, which would be replicated on the live strips when they are printed, allowing them to be corrected.

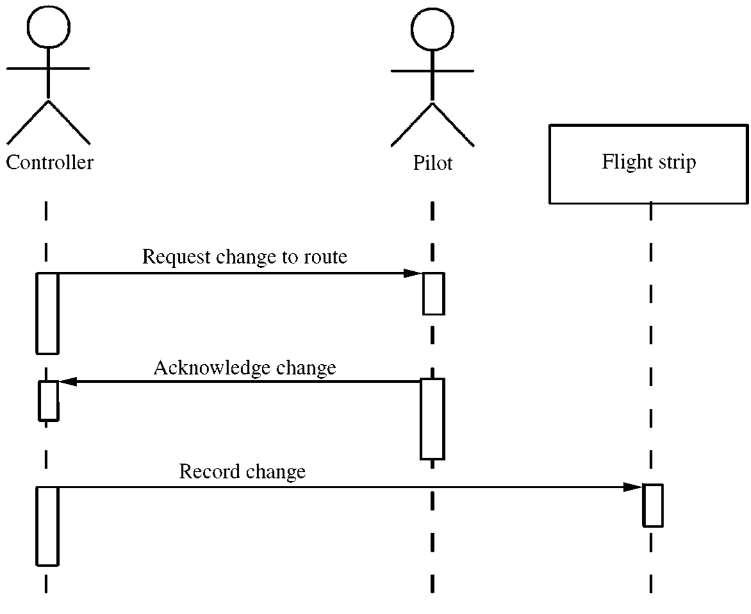

FIGURE 7. Sequence diagram for abstraction of flight coordination.

- They can be used in lieu of live strips when they are not printed in time.
- The elapsed time information on the pending strips can be used to calculate the estimated time of arrival (ETA) for hand-written live strips (used when the computer system becomes unavailable).

One of the features of both live and pending strips is that they are routinely annotated by controllers, typically to record the changes to the flight as a result of it being coordinated as in the above example (Figure 6). Elaboration of the Paperwork and Computer Work concern above (Table 9) noted this, and also remarked that because each controller uses a different colour pen to make annotations, each modification can be identified with the controller who made it. We can model this in UML by using an association class attached to a `modified by` relationship between `FlightStrip` and `Coordinator`. This is presented below in Figure 8, along with the `FlightStrip` class hierarchy described above. Other information gained during viewpoint analysis regarding the social features of the workplace can similarly be modelled making use of the extensions built into UML (for examples from a Training Centre Office, see Viller & Sommerville, 1999*a*).

Figure 8 also features a class `DeadStrip`, which has not been mentioned before now. Once a flight leaves a sector, the flight strips referring to it are removed from the racks, and placed in a bin for collection by the assistant controller. These strips cannot be destroyed (in the words of one of the controllers involved in the study "the strips are legal

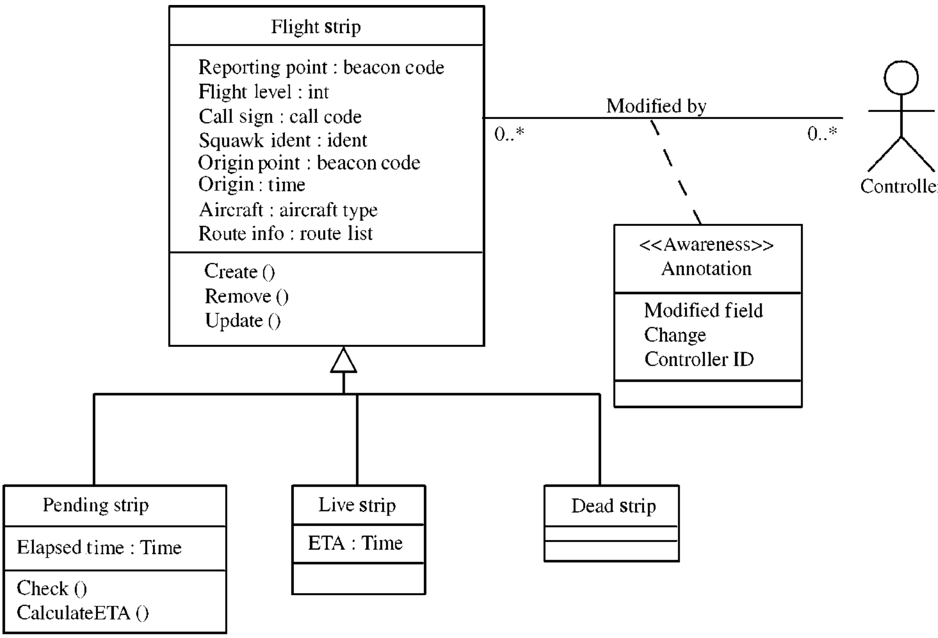

FIGURE 8. Awareness of modifications made to Flight Strips in UML.

documents") but must be stored for possible future scrutiny. Once they become dead, strips can no longer be modified in any way.

6. Conclusions

This paper has presented the Coherence approach to social analysis in systems design, which builds on our experience of working with ethnographers in a variety of domains. The approach taken in Coherence is to use a viewpoint-oriented requirements engineering technique to structure the categories of social phenomena that have arisen from previous studies, and apply them to new situations.

Our identification of social viewpoints and concerns was arrived at as a result of numerous studies in different application domains. These have shown the social perspectives to be important. However, we do not claim that they are necessarily universal nor that there are no other important social viewpoints. The viewpoints are used here as a means of sensitizing the analyst to a number of social issues that may be applicable for the workplace under study. They are not a substitute for observation, or other activities that support the process of understanding the workplace.

Nevertheless, the strength of Coherence is in developing an understanding of the current system and how it functions, with particular reference to the social interaction between people in the workplace. In this sense, it is less likely to lead to revolutionary change, but rather to constraints on future systems designs (or at least issues that must be addressed). In OOSE terminology, Coherence therefore contributes more to the requirements model, which is concerned with the current system, rather than the analysis model, which describes the new system to be designed.

The key features of Coherence are the following.

- Social viewpoints and concerns sensitize the analyst towards particular social phenomena that have repeatedly appeared in previous ethnographic studies. The key social viewpoints are distributed coordination, plans and procedures and awareness of work.
- A background or training in sociology is not required to use the approach.
- Social viewpoints and concerns structure the social analysis so that social requirements can be considered along side requirements from other sources.
- The process can be followed on its own at the start of any requirements process, but it builds upon, and links directly to, the existing PREview process.
- Links are provided to an industry standard modelling approach (use cases) and notation (UML) which are used to describe social interactions. This allows ethnographically informed requirements to be integrated into industry standard models. Further, Coherence facilitates the identification of use cases and objects in the models—a traditionally difficult aspect of these approaches.

The ATC example illustrated the type of requirements that Coherence analysis can identify. These requirements are particularly concerned with, in this case, the way that controllers coordinate their activities in order to get their work done. For example, it is obvious from the analysis presented here that the paper flight strips perform far more than a simple representation of each flight as it enters, crosses and leaves a sector of airspace. The strips are also used in a variety of ways to inform controllers of their current and future workload, of upcoming problems to be dealt with, of the workload of neighbouring sectors, and so on. Many of these functions are possible because of the paper-based nature of the strips, and the physical layout of the workplace. Any design for an electronic version of the strip, where controllers work on a screen rather than with strips of paper, would need to take such features into account.

We have found from this case study that use case models can be easily generated from Coherence analysis, providing a straight-forward route into an established approach to systems design. A strict interpretation of the definition of a use case (and therefore sequence diagrams describing them), however, implies that only one actor can be involved in one use case. It is only a minor deviation to allow for messages to pass from one actor to another. It is arguable whether such messages would be deemed to be part of the system being designed, but they are definitely part of the interaction and their representation therefore assists in the understanding of the problem as described in the models. Exploring the route into object modelling has reinforced our earlier findings, based on a study of a Training Centre Office attached to a hotel (Viller & Sommerville, 1999*a*). In this previous work, we had been concerned to demonstrate that UML was a suitable choice for representing social features of workspaces. In carrying out the study reported in this paper, we moved away from concerns with notation, towards the process by which analysis should take place.

The next work to be carried out on Coherence is the application of the method in a novel situation. The ATC case study in this paper has served to illustrate the feasibility of the approach in a well-understood domain. This has demonstrated that the fundamentals of Coherence seem suitable for the representation of social features of workplaces. We now need to turn our efforts to the support that Coherence provides the analyst in more novel situations where existing fieldwork has not been undertaken. The fact that Coherence is built upon PREview, which is a viewpoint-oriented approach to RE that has already been used with industrial partners, strengthens our conviction that Coherence offers a well-founded approach to incorporating ethnographically informed requirements into the RE process. It does this in a manner which allows the requirements to be considered alongside other requirements from other sources in such a way that the design of resulting systems can themselves be informed by an understanding of the social nature of the workplace. Our future work will be focused upon the support that Coherence provides for requirements elicitation where existing detailed ethnographic fieldwork has not previously been undertaken. In particular, this will require a more detailed description of the process of applying Coherence.

7. Further Information

More information on Coherence, COMIC and REAIMS projects can be found at `http://www.comp.lancs.ac.uk/computing/research/cseg/projects/`. In particular, interested readers are referred to the Coherence project web site for a process document which presents the example in more detail.

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