Work Domain Analysis for Distributed Information Spaces

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Abstract

In complex socio-technical systems such as military Command and Control (C2), many individuals must work with distributed and dynamic information from diverse sources. C2 systems now in use have evolved from times when information available to command was less extensive and less dynamic. The resulting information systems are not as efficient or effective as they need to be for our contemporary, information-rich environments. Typically, they are overmanned, with an unsystematic distribution of functionality and poor (even nonexistent) representations of global situation status, high level purposes and interactive dependencies between distinct functions. Cognitive Work Analysis is a formative analytic method that supports a revolutionary approach to design of complex systems. In this paper I discuss the approach of Cognitive Work Analysis and detail the use of one of its tools, Work Domain Analysis, in the design of an Ecological Interface for the USAF work domain of Special Assignment Airlift Mission planning.

Introduction

Special Assignment Airlift Mission (SAAM) planning is an activity undertaken in USAF Air Mobility Command in response to a request from another military unit to move equipment and personnel by air. SAAM planning is a complicated activity that must take into account issues such as matching of load to currently available aircraft, landing in and over-flight of foreign nations, competing airlift demands, airfield constraints, air refueling requirements, and aircrew constraints. This paper reports a part of the work undertaken for a project in which we developed a workspace design for the SAAM planning system. Based on information made available through a Cognitive Work Analysis, we developed an interface prototype in which multiple View-Ports house distinct functional requirements and in which options are made available to link various View-Port functionalities in the planning process. In this paper we show how we identified essential functionalities and their interactions.

Cognitive Work Analysis is a systematic and comprehensive method for establishing the human-system integration requirements for a work domain (Rasmussen, Pejtersen & Goodstein, 1994; Vicente, 1999). It is a multistage analytic framework that identifies functional requirements, functional resources and functional opportunities at several levels of abstraction and then identifies what must be accomplished in that work domain and the decisions and strategies that might be used. To complete the analysis, patterns of human organization and cooperation and styles of human cognitive functioning are identified. In summary, by use of Cognitive Work Analysis, analysts seek to describe the structure of the work domain, to ascertain what is to be accomplished, to identify an effective organizational structure, and to establish roles for people and for technological supports.

Cognitive Work Analysis is promoted as an analytic framework that can be applied to any human centered system whether dominated by physical constraints (e.g. a power generation plant), intentional constraints (e.g. a library catalogue), or a mix of physical and intentional constraints (e.g. military Command & Control). A strong claim of generality is embedded within its foundational assumptions (Vicente, 1999). In addition, the constraint-based approach of Cognitive Work Analysis is one that can cope comfortably with the scale-up problem. Indeed, the potential benefits from a Cognitive Work Analysis grow as systems become larger, more technologically sophisticated, and more complex.

An Ecological Interface is one that reveals the operation of underlying system processes, the interactions between system states, and the constraints on action. It is termed ***ecological*** specifically because it presents constraints and thereby permits workers to develop their own courses of action. An ecological interface encourages workers to operate within a space of potential action and leaves them free to develop solutions to complex patterns of events that cannot be fully anticipated. In contrast, a conventional interface presents individual parameters of system states that guide workers through set courses of action and leave the operator with the task of integrating those parameters into a meaningful interpretation of system function. This is a task that is cognitively demanding and one that may become impossible under tight time constraints.

While an ecological interface presents more information than the conventional interface, it does not overload the operator because that information is integrated across levels of abstraction and the interface supports natural and compatible navigation that allows operators to converge naturally on momentarily important constellations of information. The intuition behind the development of an ecological interface is that it should correspond in its design to natural information-action workspaces that support robust, effective and adaptive performance. As in a natural space, the information will be organized at different levels of abstraction and detail. Furthermore, that information will be summarized and represented in forms that can be directly associated with functional action.

The Unique Value of Cognitive Work Analysis

Cognitive Work Analysis has been developed specifically for analysis of complex, large-scale, socio-technological systems. It is the only human-oriented analytic method that takes full account of intentional as well as physical constraints, those constraints inherent in:

- The physical and purposive nature of the workspace
- The specific goals of the work
- The technological resources
- The human actors
- The organizational structure

Furthermore, Cognitive Work Analysis has been developed specifically for systems in which human work cannot be proceduralized because of the functional consequences of unpredictable events. Much Human Factors design is focused on a normative approach that specifies how a human worker should react in predetermined scenarios. In contrast, Cognitive Work Analysis is used to establish how designers can reveal the constraints (both intentional and physical) on action, so that the worker is free to adapt flexibly (within those constraints) to unanticipated situations.

Large-scale systems have typically been developed through an evolutionary process where a system is engineered and then refined in operational use through an iterative or evolutionary process. Cognitive Work Analysis is the only design strategy yet available for development of entirely new forms of human-system integration. This relatively new approach to design (Rasmussen, et al, 1994; Vicente, 1999) is now being used increasingly in the design of modern, distributed military systems that are heavily loaded on cognitive and team operations (Burns, Bryant and Chalmers, 2000; Naikar & Sanderson, 2001; Rasmussen et al, 1994) and has recently been adapted to the design of military training systems (Lintern & Naikar (1999, 2000).

Design of an Ecological Workspace

The developmental strategy for an ecological workspace is to:

- Analyze the work domain
- Design the Information-Action Workspace
- Fabricate the workspace
- Evaluate the workspace

Cognitive Work Analysis forms the foundation of this design approach. It has five distinct stages (Vicente, 1999). Typically the analyses commences with the sequence of Work Domain Analysis → Control Task Analysis → Strategies Analysis. The work domain analysis identifies the essential information and suggests some aspects of how that information should be organized. The Control Task and Strategies Analyses further suggest how that information should be organized and represented by showing how it is to be used. A Social Organization Analysis and a Competencies (Levels of Cognitive Control) Analysis normally follow. The first of these identifies the patterns of interaction in the workspace while the second assesses characteristics of actors and how those characteristics influence the way they receive, perceive and act on the information.

Work Domain Analysis

A set of tools exists for knowledge acquisition and knowledge representation in each phase of a Cognitive Work Analysis. The knowledge representation tool for Work Domain Analysis, the Abstraction-Decomposition Matrix, is the one that provides the foundation for the design of a radically new system form. This matrix represents functional properties of the work domain (objects, resources, constraints, purposes, processes) in a two-dimensional matrix (Figure 1). The vertical dimension represents the dimension of abstraction and the horizontal dimension shows varying levels of decomposition.

While in principle, all cells in the Abstraction- Decomposition Matrix could have entries (each cell represents a complete but alternate description of the total system) it is rarely useful to develop entries for all cells. There must, however, be an unbroken flow through the abstraction-decomposition levels. Typically there will be only one or two levels of decomposition identified at any specific level of abstraction. It should be noted, however, that the Abstraction-Decomposition Matrix is a tool for exploration as well as for representation, and insights can often be gained by generating it in different forms.

Links between different levels of abstraction, known as means-end links, map the means-end functional relations within the matrix (Figure 1). They reveal how functions at one level are enabled by other functions at lower levels and, in turn, how functions at one level enable other functions at higher levels.

The Special Assignment Airlift Mission

The purpose of an ecological workspace for mission planning is to reveal the opportunities for assembling an effective and efficient mission. Such a workspace should present all essential information, support the necessary actions to implement decisions, and provide opportunities to test decisions in advance of implementing them. The development of an ecological workspace requires an understanding of what to represent, how to represent it, and how to organize it and that requires a deep understanding of what information is required and what must be done.

In this project, we have undertaken a Work Domain Analysis, some elements of a Control Task Analysis, and an abbreviated Social-Organizational Analysis of SAAM

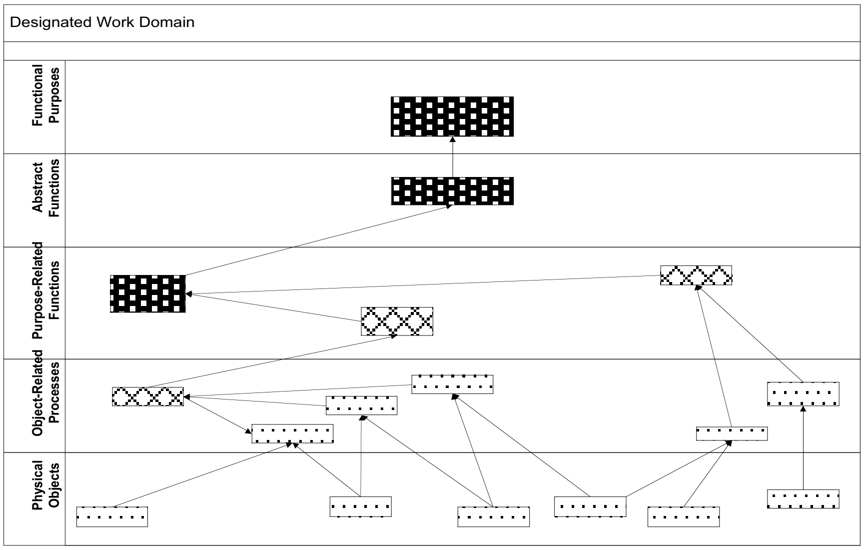

Figure 1. A prototypical layout of an Abstraction-Decomposition Matrix.

Each box will contain a functional identifier. Means-End links connect functions between levels of abstraction (vertical dimension). A decomposition of system into units is shown at the abstraction level of Purpose Related Functions and a decomposition of units into components is shown at the abstraction level of Object-Related Processes. Another decomposition of units into components is shown between the abstraction level of Purpose Related Functions and Object-Related Processes.

planning to identify the functionality (purposes, values, an abbreviated Social-Organizational Analysis of SAAM planning to identify the functionality (purposes, values, resources and opportunities), primary control tasks, and the prototypical workflow of the planning portion of the SAAM work domain. A brief account of the Work Domain Analysis is offered below.

Description of Mission Planning and its Context

Air Mobility Command trains, equips, and organizes air mobility forces, and provides them to the Tanker Airlift Control Center for use in supporting air mobility customers. Mission Planners for Tanker Airlift Control Center operate within Air Mobility and Tanker/Airlift Control Center Operations. Military customers use funds provided out of their funding to purchase airlift to move materiel, supplies and personnel overseas from continental US and back. The 'bank account' used to manage airlift funds is called the Transportation Working Capital Fund. However, the Commanders in Chief and Services also tend to use other funds allocated for surface or sea transportation to move high priority materiel and personnel by air. There is always more demand for airlift than there are aircrews or aircraft to fulfill it, which results in a need for prioritization.

Air Mobility Command flies five types of routine missions. A Special Assignment Airlift Mission (SAAM), which is the mission type chosen for examination within this project, is a charter of entire aircraft to move materiel and personnel between points not served by the Channel (regularly scheduled) routes. Customers are billed by the flying hour it takes to move their loads. A customer sends a requirement specification to the United States Transportation Command to initiate a SAAM. Transportation Command then tasks the Tanker Airlift Control Center to support requirements that are eligible for air movement by policy and for which the customer has funds to reimburse the Transportation Working Capital Fund.

The SAAM planning shop is responsible for planning the mission. The planning process generally flows as follows:

- Analyze requirement and determine a mission outline
- Determine tentative routing & determine resources required
- Request resources (from operational units)
- Develop the plan within the scheduling form that lays out mission details (Form 59)
- Publish the plan when the schedule is finalized

At this point, active involvement of the SAAM planner is finished but information on mission progress is available to the SAAM planning shop and there may be a need for re-planning if there are disruptions to the initial plan.

These planning steps can be described in more detail in terms (where relevant) of a general summary of activities, required resources, mission duration, mission support requirements, mission timing cycle and possible agent functions. A detailed analysis of the functional structure of Mission Planning follows.

Analysis of Mission Planning

Within Cognitive Work Analysis, the functional structure and the decompositions of a work domain are identified via Work Domain Analysis and are represented in an Abstraction-Decomposition Matrix.

Decomposition of Mission Planning. The analysis was constrained to investigation of an individual SAAM mission, which constitutes an initial decomposition. The load-handling domain and the flight domain were then analyzed separately (Figure 2), which is a further decomposition. For purposes of representation, the single mission was identified as the System level of decomposition and that system level of description was decomposed into Units at the abstraction level of Functional Purpose. Units are further decomposed into Components at the abstraction level of Abstract Function. This degree of decomposition is maintained at the abstraction level of Purpose-Related Functions but a further decomposition into Parts is applied at the abstraction level of Object-Related Processes. This degree of decomposition is then maintained at the abstraction level of Physical Objects.

Strategy of Functional Analysis. Separate Abstraction-Decomposition Matrices were developed for two different components (Flight Management and Load Management) to simplify the representations and to allow them to be depicted in legible form on a single page. However, these pragmatic strategies introduce a concern that important interrelationships between functions will be neglected. The attention paid to these sorts of relationships is one of the particular advantages of this style of work analysis.

Nevertheless, the strategy employed here resulted in an analytic product that could be used as a building block for a more complete analysis of the whole system in which those important interrelationships might then be identified. In addition, although represented separately here, the two Units of the SAAM were analyzed together and I have identified interrelationships between them by showing common functions in both matrices. The five levels of functional structure identified in the Abstraction-Decomposition matrix are:

- **Functional Purposes**: A SAAM planning effort has two purposes, one is to develop a plan for airlifting materiel, supplies and personnel and the other is to set out the details of the plan so that the rationale behind it is apparent to all stakeholders. The analysis revealed that the planner faces three main issues, the first being to take care of the load, the second being to take care of the aircraft and the flight, and the third being to integrate the mission currently under planning with other missions that might compete for or share resources. The analysis as presented here uses separate matrices to depict the sub domains of the flight and the load. The third sub domain of coordination with other missions was not analyzed in this project.
- **Abstract Functions:** The causal structure of mass, energy, information, or value processes are shown at this level. This causal structure is typically described in terms of sources, sinks, flows, conversions, conservations, balances and constraints. A feature of this analysis is the demonstration that these concepts (drawn from analysis of physical processes) are useful for analysis of intentional systems.
- **Purpose-Related Functions:** These are the basic functions that the work domain is designed to achieve. For mission planning, these are the elements of the plan that make it workable.
- **Object-Related Processes**: Details that must be considered in the development of the plan are represented here.
- **Physical Objects:** Physical objects, physical layouts and sources of information are shown here. Particularly at this level, many of the entries are system elements that might be eliminated or modified in a re-design effort.

Figure 3 shows a fragment of the Abstraction- Decomposition matrix developed for the work domain of the load. It spans the top three levels of abstraction. Stakeholders who act on this domain under the current organization of SAAM mission planning are the customer, the SAAM Mission Director, and the SAAM Planner.

Principles of Workspace Design

Analysts often appear to assume that the products of an analysis either constitute design specifications or that the design specifications fall naturally out of the analysis. This is, in fact, a problematic issue. It is one that has not been given its due attention in part because analysis and design are frequently undertaken as independent endeavors. Where design is preceded by systematic analysis, an implicit process typically guides the transition from analysis to design. The result of the design effort may be commendable but the method of transitioning analytic products into design decisions remains obscure. In this project we sought not only to transition our analytic products into design features but also to show explicitly how it was done.

Design of a workspace requires attention to issues of content, form and layout. The first of these relates to the information that is to be represented in the workspace, the second to selection, adaptation or creation of perceptual forms for the required information content, and the third to the design of the spatial and temporal layout of the information and the requisite forms of navigation. There are different sets of design principles for each of the analyses undertaken within the framework of Cognitive Work Analysis. Here we discuss those relevant to Work Domain Analysis.

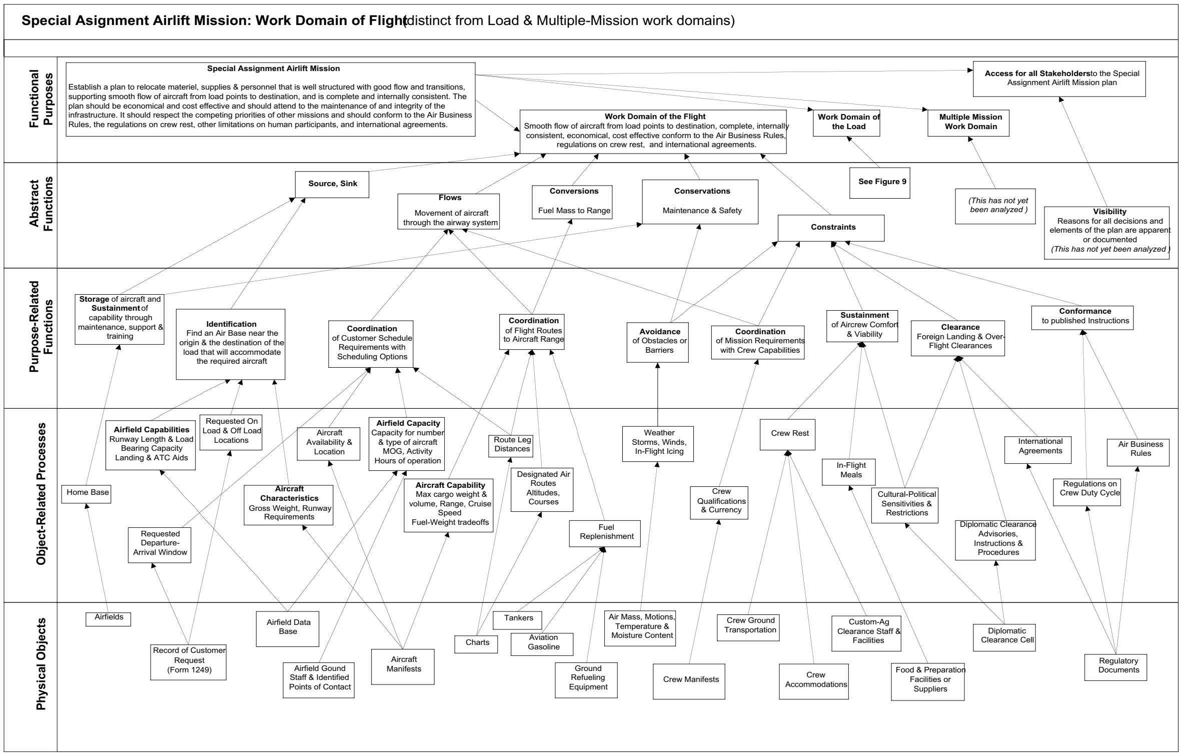

Figure 2. The Abstraction-Decomposition matrix for the work domain of the Flight for SAAM mission planning

The Abstraction-Decomposition matrix identifies objects, resources, constraints, purposes, and processes at various levels of abstraction. Information specific to every function represented in that matrix must appear somewhere in the workspace. The means-end links of the matrix and the decomposition links show the essential navigation paths that must be supported within the workspace. Burns (2000) has shown that navigation along means-end links may be layered so that the workspace user can go behind a display to get means information about an end. On the other hand, navigation along decomposition paths should be between View-Ports that are displayed concurrently.

By use of these principles, together with those related to the other components of Cognitive Work Analysis, it is possible to develop the content, form and layout for an ecological workspace that supports normal and problems solving activity at skill-, rule-, and knowledge based levels. Lintern, Miller and Baker (2002) offer an example of such a workspace for SAAM planning that is the result of using these principles to transition from analysis to design.

Summary

In this project we have developed a systematic, verifiable and explicit approach to Work Centered Design and have applied that approach to the design of a workspace for USAF Mission Planning within Air Mobility Command. Our report of the project work outlines several innovative contributions:

- The use of Cognitive Work Analysis to develop a comprehensive representation of functional requirements for the human-system interface,
- An explicit account of the transition from analysis to design, and
- A method, based on the approach of Ecological Interface Design, for design of a use-centered information-action workspace.

The approach we have outlined here builds on the growing body of research and development in Cognitive Work Analysis and Ecological Interface Design. Although Cognitive Work Analysis constitutes a relatively small segment of the overall body of Human Factors and Human-System Integration research and development, it is becoming apparent that this approach is unique in its capability to deal with large, complex socio-technical systems. Much of that work has, however been undertaken in the context of systems in which physical processes dominate the causal interactions, and the example provided here of the application of the method to a system in which intentional and informational processes dominate offers a valuable example of the applicability of this approach to the complex and distributed information systems that now dominate military operations.

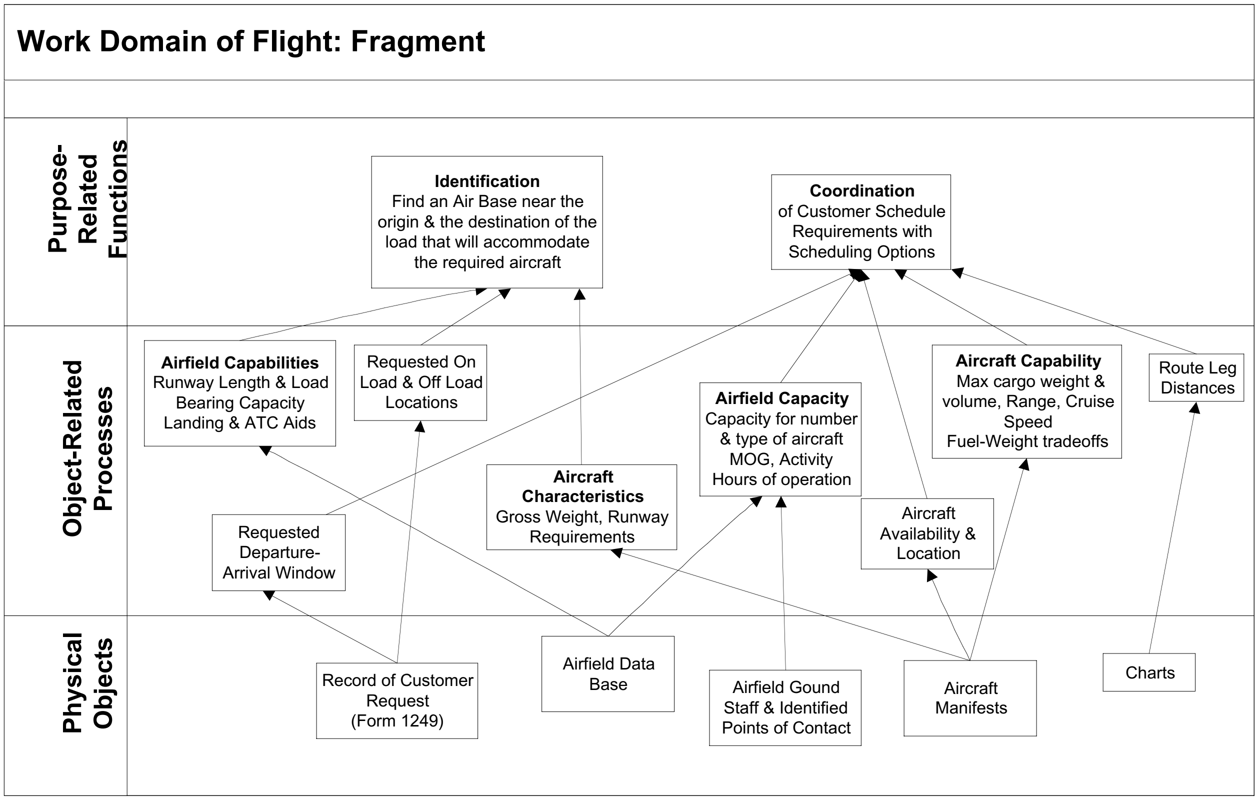

Figure 3. A fragment of the Abstraction-Decomposition matrix for the work domain of Flight for SAAM mission planning.

Acknowledgments

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