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Human Performance Modeling for Enterprise Transformation

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Abstract. Satisfaction of current demands for increased efficiency in the use of human resources requires nothing less than a revolutionary transformation in how we structure complex socio-technical systems. Human systems issues related to transformation of complex socio-technical systems pose substantive design challenges that must be addressed with human–centric analysis followed by human-centric design. In this paper, I integrate a cognitive work analysis strategy with a human performance modeling strategy which, when combined, constitutes a systematic, human–centric analysis-to-prototype design framework. I have described the cognitive work analysis strategy elsewhere and in this paper focus my discussion on cognitive workflow modeling. I illustrate the requirements of human performance modeling and methods of satisfying them with reference to a Brahms workflow model of time sensitive targeting based in part on a functional abstraction space developed within a cognitive work analysis and use that workflow model to motivate discussion of issues related to human-centric design for enterprise transformation.

Enterprise Transformation

Rapid development of information technology has enabled functional transformation in some highly competitive commercial enterprises. Although the defense industry lives within this new competitive environment and seeks to exploit the transformational possibilities of new technologies, it remains locked within a cultural environment that sustains outmoded work processes. The distortions that result from integrating outmoded work processes with revolutionary functions often border on the absurd but enterprise transformation is first of all, difficult to envision and then, within organizational structures that require consensus of diverse constituencies, difficult to implement.

Rouse (2005) has addressed several of the challenges for enterprise transformation. Here I focus on one specific concern; that a techno-centric worldview, with its commitment to rationality and logic, is so pervasive in our military and defense acquisition cultures that the scope of transformation will inevitably be limited and the gap between potential and realization will continue to expand. A more human-centric view is required and that can be possible only when the fundamental distinction between human and technological functionality becomes embedded in our transformational design theories. The promotion of that distinction is nevertheless, a challenge. Aided and abetted by behavioral scientists whose dominant theories of human cognition rely on technological concepts, engineers inevitably conceptualize human functionality in terms of technological functionality.

Enterprise transformation requires a conceptual transformation in how we think about the integration of humans and technology; a conceptual transformation with the power to pervade the engineering disciplines involved in the development of socio-technical systems. However, those locked in a techno-centric worldview sensibly question how it could be different and with such strong commitments to a technological worldview, the potential of dialogue and reason to promote transformation is limited. Those of us who wish to promote a human-centric transformation need to offer an evocative vision and must find means other than dialogue and reason to promote it.

We thus face a dilemma; we wish to transform a worldview that is so deeply embedded in our design culture that it will not respond to dialogue or reason. We not only need to envision a new way but we need to instantiate it in forms that capture the imagination of those we wish to influence. Computational modeling offers a possibility. This discipline has emerged with the growing capability of information technology and now has considerable influence in all branches of science and engineering. Although the directions taken by computational modeling have been guided predominantly by the techno-centric worldview, I discuss in this paper a modeling system based on a human-centric theory of cognition and will demonstrate how it can be used to model cognitive workflow and the role such a model can play in development of a complex, socio-technical system.

A Vision for System Design

The ideas developed here are consistent with but extend many contained in the draft technical vision of the International Council on Systems Engineering (INCOSE, 2005), which anticipates expanding interest in systems thinking driven by a trend towards larger, more complex systems and by demands to do more with fewer resources. The INCOSE vision stresses a design approach that starts with the development of system architecture followed by specification of requirements and prototype development. That vision further notes a need for greater attention to non-traditional methods of exploring emergent and adaptive behavior and better synthesis techniques that can produce more robust and balanced system solutions.

The INCOSE (2005) vision notes an emerging recognition in Systems Engineering for human roles within socio-technical systems. It identifies the self-adaptive nature of humans as one of the motivations for developing better tools to cope with the increased complexity of systems design that results when human agents are responsible for significant portions of the system functionality. Ring (2004) argues that although current Systems Engineering practice can be applied effectively to the design of inanimate systems, it faces significant obstacles in the design of human intensive, socio-technical systems. The lack of design knowledge about how to support human cognition is part of the problem but the failure to design effectively for the self-adaptive and self-organizing role of humans, the primary reason for retaining them in modern systems, is the more fundamental problem.

A Human-Centric Design Strategy

The human-centric design strategy I promote here is one that commences with a comprehensive and systematic analysis of cognitive work (Vicente, 1999; Rasmussen, Pejtersen & Goodstein, 1994; Lintern, in press). The results of this analysis are used to develop a workflow prototype, which is first used as a design artifact to explore design possibilities and then as a candidate system to be evaluated via Human-in-the Loop simulation. The prototype could, in principle, be instantiated in various forms, but computational modeling is the most efficient and flexible form currently available. Consistent with the draft INCOSE vision (2005), I argue for the use of computational models to instantiate operational prototypes of detailed system processes, with the caveat that where those system processes are predominantly ones of cognitive workflow, a human-centric modeling strategy is essential.

The project described here builds on previous work by Lintern and Miller (2003) and Lintern (2005). Lintern and Miller (2003) proposed a design strategy for Human-Systems Integration that combines cognitive analysis and computational modeling within the standard defense process for acquisition of complex military systems. The cognitive analysis was directed at identifying the implications for system architecture of the cognitive demands inherent in mission operations. The results of that cognitive analysis were to be used to develop system architectures that took account of those cognitive demands. Those results were also to be used to develop demanding evaluation scenarios; the term *edge case* was coined to characterize scenarios that push the system to its reasonable limits. Proposed functional architectures were to be evaluated first by testing *edge cases* within a computational constraint-checking model known as PlayBook and then by testing surviving functional architectures with selected *edge cases* via Human-in-the-Loop simulation.

Lintern (2005) further developed this strategy but in doing so, substituted the Brahms simulation environment for the Playbook constraint checking system. Brahms can be used to model workflow and significantly for this project, to model cognitive workflow. It has a number of features that promote it as the modeling tool of choice but primarily, it permits modeled human agents to be selectively substituted by actual human agents to convert the computational simulation of cognitive workflow into a Human-in-the-Loop simulation. The potential benefits of this capability for design of complex socio-technical systems are considerable. Cognitive processes are as yet so poorly understood that Human-in-the-Loop simulation is an essential verification of results found in computational modeling of cognitive processes. In general, that requires fabrication of a physical prototype, which in itself, is a resource intensive project.

The general design strategy promoted for this project is that cognitive analysis precedes computational modeling, which in turn precedes Human-in-the-Loop simulation. By use of Brahms, it becomes possible to execute the Human-in-the-Loop simulation with the same computational prototype used for the computational modeling. Signal flows within the computational model are intercepted at appropriate points and diverted to interfaces for human operators. Signals from human action at these prototype interfaces are then reinserted in the model at appropriate points. Essentially, the interface with its human operator can be used to bypass selected computerized agents. Although the design process has a sequential flow from analysis to computational modeling to Human-in-the-Loop simulation, it conforms in practice to the strategy of spiral development.

Computational Modeling

What is a Computational Model? There is some confusion in different areas of scientific literature about what constitutes a model. Within behavioral science, *model* and *theory* are often treated as synonyms (Lachman, 1960). In Cognitive Engineering, many refer to static representations of structure, process or activity as models. For this project, I follow the views of Jackson (1990) in taking a computational model to be a realization of a mathematical or logical structure.

Physical Modeling. Techniques for modeling physical systems have developed considerably since computers have become ubiquitous within science and engineering. These developments have had less to do with fundamental advances in scientific knowledge or computational methods than with the sheer convenience of computer-based modeling tools for exploration of computationally intensive processes.

As an illustration, consider the problem of establishing the thermal efficiency of a home. The essential algorithms are well understood as are the relevant physical processes. In addition, the resistance of materials to the passage of heat can be measured to acceptable levels of accuracy. The current cost of energy to heat and cool is also known and so one could, for example, use an energy efficiency model to assess whether the expense of upgrading insulation would be cost-effective in today's terms. Some important complexities are also well understood. For example, temperature maintenance in summer is not the inverse of temperature maintenance in winter. As an exercise in modeling, the conceptual issues are at least tractable.

The problem becomes more challenging if one wants to project into the future. Will an upgrade now pay off in the long term? This requires some assessment of the future cost of energy in contrast to potential return on investment for money not diverted to an upgrade. Essentially, is the upgrade a better investment than other possibilities? The quality of a preferred investment vehicle may change considerably in just a few years. Rules of thumb might be used but are precarious approximations at best. Effective modeling of this sort of issue is challenged less by the validity of computational models than by accurate specification of input parameters.

The input parameter problem is not, however, the only one that challenges human performance modeling. The most intractable issue for human performance modeling is the instability of human functionality. In the design of energy-efficient homes, we can at least be assured that thermal properties of insulating materials are consistent and stable. Ponder for a moment the challenge if different samples of the same materials varied widely in their thermal resistance. Add the possibility that thermal resistance of those materials degraded over time and especially if that degradation was unpredictably nonlinear. This, specifically, is the type of challenge that faces human performance modeling where cognitive capability and capacity can change with stress, fatigue and experience. Sometimes the direction of change can be unexpected, as for example for team performance under high workload (Serfaty, Entin, & Volpe 1993).

Human Performance Modeling. Provocatively perhaps, I offer that the focus of most human performance modeling has been on methods and issues derived from a techno-centric worldview. The model structure is typically motivated from a mathematical or logical formalism and modeling issues not conceptually tractable in such a framework are excluded from consideration. Human error and workload are seen as paramount issues and automation is a preferred solution. I do not believe that human error and workload are paramount issues within Human-System Integration or that human performance modeling strategies developed from a techno-centric worldview will provide the essential insights needed to design for human participation in socio-technical systems. In particular, a techno-centric worldview has serious limitations as a basis for addressing design issues involved in enterprise transformation.

For a large-scale socio-technical system such as a USAF Air Operations Center, the focus of modeling needs to be on the flow of cognitive work, for example how decisions are made and how information is acquired, exchanged and stored for later use. In addition, it is necessary to model how the cognitive work is scheduled, for example, how various cognitive tasks are distributed among agents and how individual agents schedule their own responsibilities.

The modeling tool selected for this effort is Brahms, a multi-agent modeling and simulation language for work system analysis and design (Clancey, Sachs, Sierhuis & van Hoof, 1998). It differs from other human performance modeling tools in that its design was motivated by a human-centric theory of human behavior, the theory of Situated Cognition (Clancey, 1997) rather than by a mathematical or logical formalism. A significant assumption of the theory of Situated Cognition is that human activity is subsumed within and shaped by context and that most activity is shaped by loosely coupled constraints between several levels of hierarchically nested contexts (Figure 1). The Brahms simulation environment instantiates this assumption as a hierarchical subsumption architecture of work frames and activities.

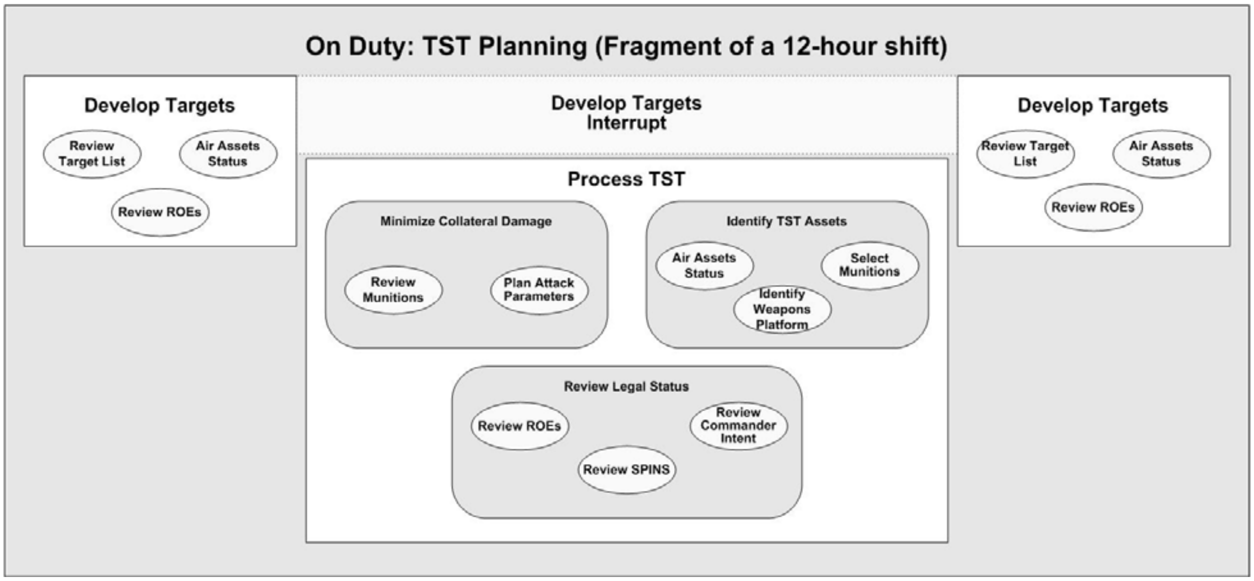


Figure 1. A subsumption diagram of planning for Time Sensitive Targeting: within the context of being on duty, this agent is generally in the subsumed, generic context of target development but will transition to a target processing context on demand and, within that context, will execute the required activities.

The important modeling capabilities of Brahms are:

- **Workflow interruption**. As is common in normal work, a high priority event can interrupt ongoing work. The interrupted work may be aborted or it may be suspended and then resumed once the higher priority demand has satisfied.
- **Communication**. Human agents and information objects can communicate with each other to guide, inform or alert.
- **Record creation**. Information objects can be created and then updated by various agents.
- **Decisions**. Human agents can make decisions based on information they receive and on the information sources they review.
- **Contingent action**. Human agents react to the decisions they make and also to information they receive from other sources.

In the next section of this paper I discuss how these capabilities were used to model cognitive workflow for Time Sensitive Targeting in an Air Operation Center.

Air Operations

The Air Operations Center, a large-scale military Command and Control system that employs several hundred service and technical personnel, is the domain of interest. An Air Operations Center is a complex information system that is rich in cognitive demands. It has evolved in parallel with advances in information technology but that evolution has been fragmented. There is now considerable interest in redesigning the system to support fully integrated analysis, planning and execution. Much of the discussion surrounding this call for redesign sounds like a call for enterprise transformation but has typically had a techno-centric focus on technological innovation absent any human-centric treatment of functional restructuring or cognitive workflow.

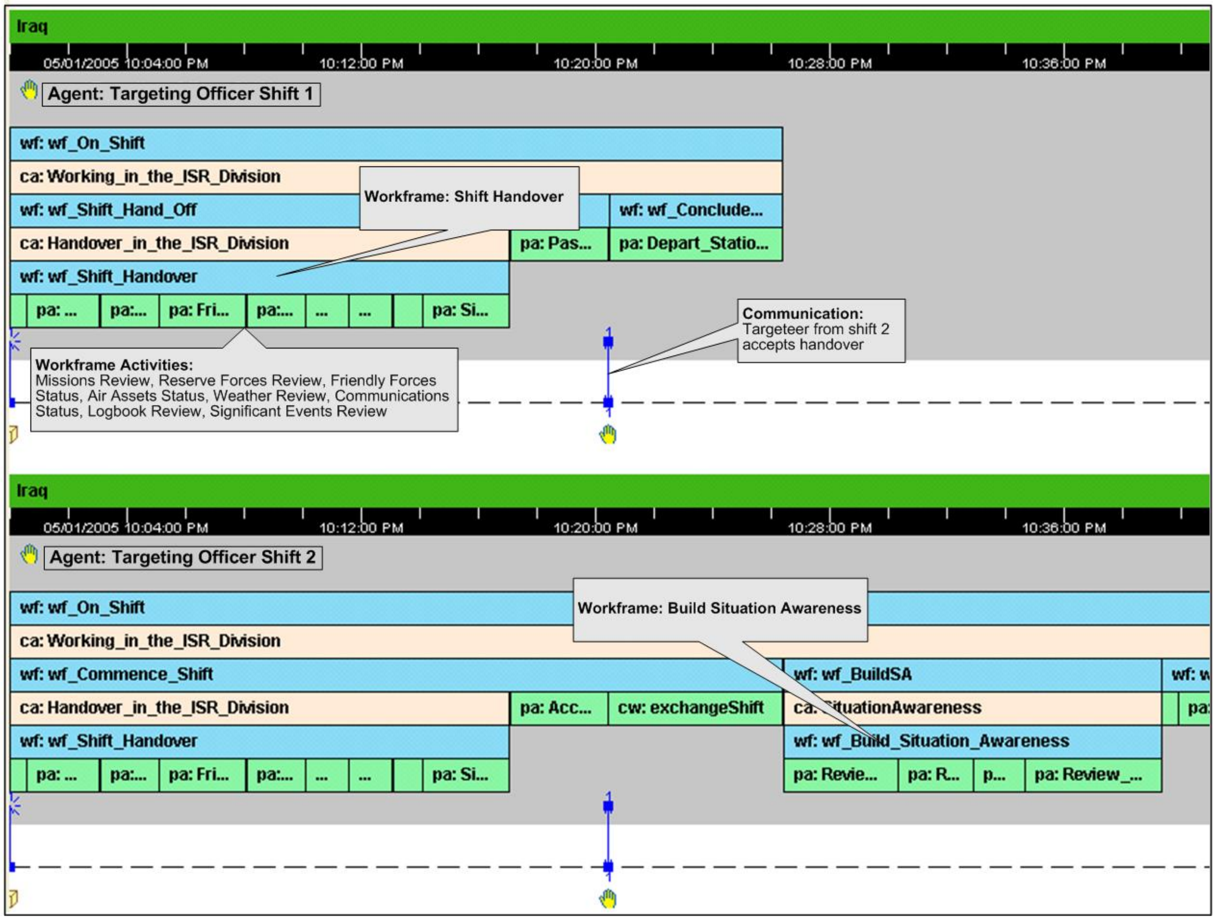
Time Sensitive Targeting was selected as the focus for this demonstration effort. Raw cognitive data were gathered from documents and from interviews with subject-matter experts. The prime concern for this paper is to demonstrate that the Brahms modeling approach can take account of significant features of cognitive workflow and cognitive work activity rather than with an accurate rendition of Time Sensitive Targeting. The cognitive analysis of Time Sensitive Targeting is not yet complete and some features of this model have been fabricated to complete the workflow narrative.

The Time Sensitive Targeting cell is located in the Operations Division and is staffed by a Cell Chief, a Targeteer, a Rerole Coordinator, an Attack Coordinator and a representative of the Judge Adjutant General (JAG). The scenario modeled here also involves a Targeting Officer located in the Intelligence Surveillance and Reconnaissance (ISR) Division and an information system, the Automated Deep Operations Coordination System (ADOCS). Although Brahms can model the properties of diverse communications systems, a generic communications net was used to simulate communications flows in this model.

A 12-hour work shift is modeled. Each agent on the modeled shift has a contemporary from whom they accept the shift. A shift transfer is modeled as a series of information exchanges on different topics (Science Applications International Corporation, 2001) and ends with a communication exchange between the two agents (Figure 2). The next task for the agent taking over the shift is to build situation awareness related to current operations. Once an agent is satisfied with her/his level of situation awareness, s/he engages in generic activities.

Information about potential Time Sensitive Targets arrives at the Air Operations Center at irregular intervals. The entry of a Time Sensitive Target to the system initiates a series of identification and planning activities, some undertaken sequentially and others in parallel, by various members of the ISR and Operations Divisions.

Processes for identifying Time Sensitive Targets in the Theater of Operations and then transmitting information about them to the Air Operations Center are not represented in this model. That information is created by a generic Field Agent to seed the modeled workflow. Incoming information specifying target type and location described in terms of proximity to well known physical features is recorded in a field report and assigned to a vacant target slot in the information system. Targets are subsequently identified by the numerical designation for their respective slot. Each slot has the capacity to record a pre-specified set of target attributes, all of which are set as *unspecified* or *unknown* at the initiation of the simulation. Thereafter, these attributes are converted by the different agents into values specific to the particular target allocated to that slot.



Workframe: Shift Handover

Communication:
Targeteer from shift 2
accepts handover

Workframe Activities:
Missions Review, Reserve Forces Review, Friendly Forces Status, Air Assets Status, Weather Review, Communications Status, Logbook Review, Significant Events Review

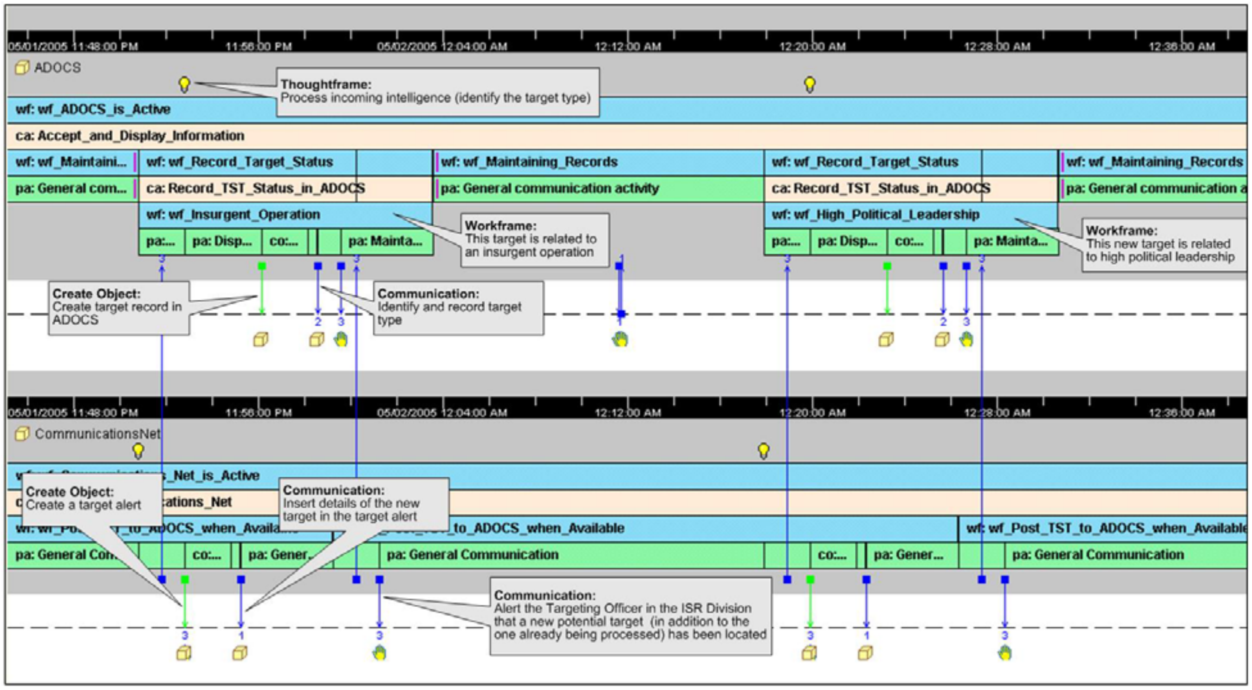
Workframe: Build Situation Awareness

Figure 2. A section of the timeline produced by Brahms for two agents, the Targeting Officer for the old shift and the Targeting Officer for the new shift (callouts added to the figure to identify Brahms output features).

The ISR Division Targeting Officer is notified (in this simulation, by the generic Field Agent) via ADOCS that a record of a Time Sensitive Target has been created and is available for processing (Figure 3). The Targeting Officer confirms the target identity and identifies its mensurated coordinates. S/he identifies its priority as previously established by instructions from the Joint Forces Air Component Commander and records that information in the ADOCS target record (Figure 4). S/he then advises the Targeteer in the Time Sensitive Targeting cell of the Operations Division that the record is available for targeting.

Figure 4 illustrates the workflow interruption feature of Brahms. The Targeteer is routinely engaged in developing generic targets except when dealing with a Time Sensitive Target. In the modeled scenario, s/he stops work on generic target development immediately s/he is alerted to the Time Sensitive Target but returns to generic target development once the higher priority demands associated with the Time Sensitive Target have been satisfied.

When advised that the Time Sensitive Target is ready for rerole processing, the Rerole Coordinator accesses the ADOCS record and then examines the availability of attack, cover, enemy air defense suppression, and refueling aircraft. S/he schedules those assets for the mission and after entering the details in the ADOCS record, advises the Attack Coordinator that the mission is now ready for the planning phase.



Thoughtframe:
Process incoming intelligence (identify the target type)

Workframe:
This target is related to an insurgent operation

Workframe:
This new target is related to high political leadership

Create Object:
Create target record in ADOCS

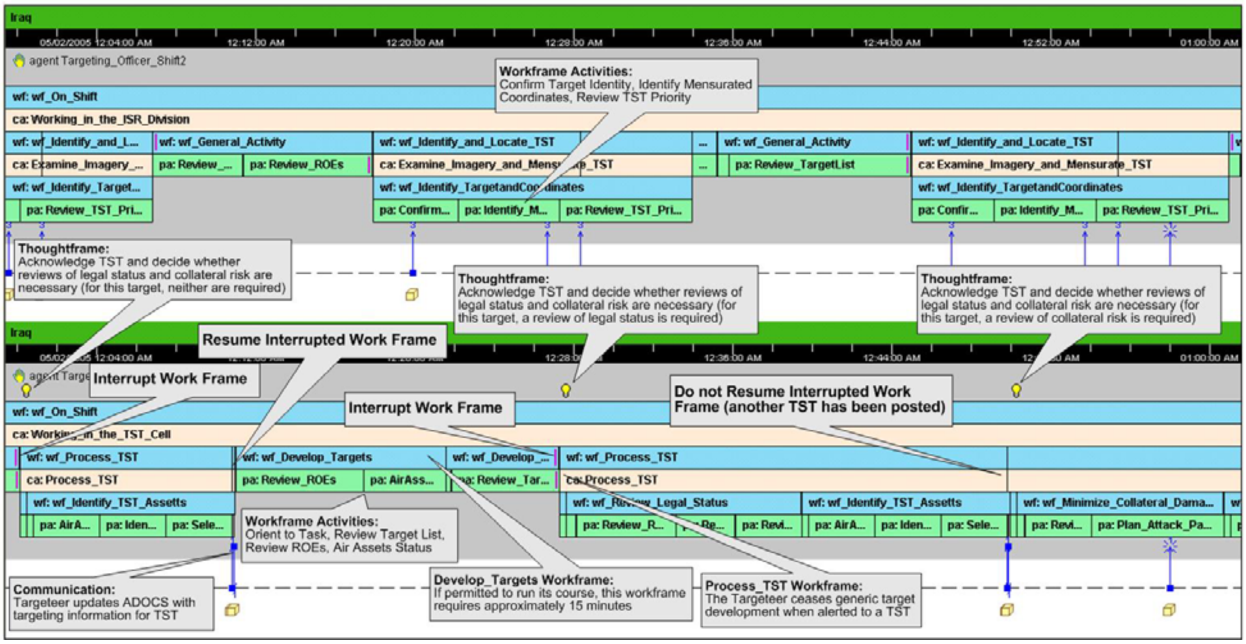
Communication:
Identify and record target type

Create Object:
Create a target alert

Communication:
Insert details of the new target in the target alert

Communication:
Alert the Targeting Officer in the ISR Division that a new potential target (in addition to the one already being processed) has been located

Figure 3. A section of the timeline produced by Brahms for two information systems, the Automated Deep Operations Coordination System (ADOCS) and a generic communications net (callouts added to the figure to identify Brahms output features).



Workframe Activities:
Confirm Target Identity, Identify Mensurated Coordinates, Review TST Priority

Thoughtframe:
Acknowledge TST and decide whether reviews of legal status and collateral risk are necessary (for this target, neither are required)

Thoughtframe:
Acknowledge TST and decide whether reviews of legal status and collateral risk are necessary (for this target, a review of legal status is required)

Thoughtframe:
Acknowledge TST and decide whether reviews of legal status and collateral risk are necessary (for this target, a review of collateral risk is required)

Resume Interrupted Work Frame

Interrupt Work Frame

Interrupt Work Frame

Do not Resume Interrupted Work Frame (another TST has been posted)

Workframe Activities:
Orient to Task, Review Target List, Review ROEs, Air Assets Status

Communication:
Targeteer updates ADOCS with targeting information for TST

Develop_Targets Workframe:
If permitted to run its course, this workframe requires approximately 15 minutes

Process_TST Workframe:
The Targeteer ceases generic target development when alerted to a TST

Figure 4. A section of the timeline produced by Brahms for two agents, a Targeting Officer and a Targeteer (callouts added to the figure to identify Brahms output features).

The Attack Coordinator schedules the mission, paying attention to such things as air refueling needs and locations of enemy air defenses. The Attack Coordinator will plan the electronic footprint required to suppress enemy radar threats and will normally need to schedule two to three aircraft with electronic suppression capability for that task. S/he will also take account of collateral damage issues and will plan attack run-in lines and attack angles accordingly. After recording that information in ADOCS, s/he will take the plan to the TST Cell Chief for approval.

The TST Cell Chief will review the plan and may consult the JAG representative to confirm its legality. The target plan is then posted to ADOCS and is now ready for execution.

The timeline shown in figures 2 to 4 is the primary output of Brahms but other output capabilities are available to examine the progress of events. Figure 5 shows the flow of Time Sensitive Targets through ADOCS. This record reveals the times at which different targets enter the system. Once a target has been passed on or a permanent record created, the system is set to "standby" in readiness for another target.

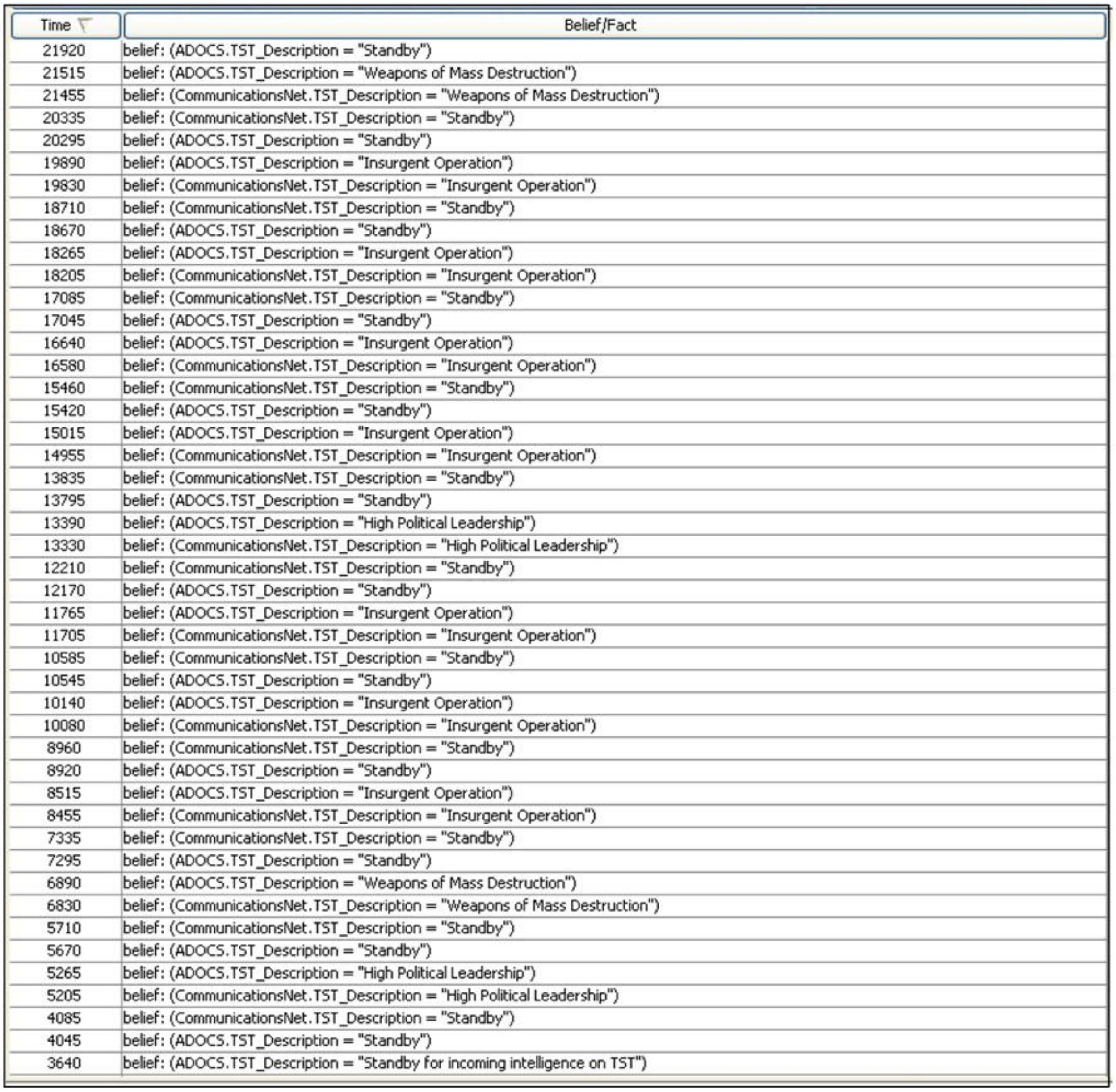
Enterprise Transformation Revisited

Enterprise transformation concerns change, not just routine change but fundamental change that substantially alters an organization's relationships with one or more key constituencies.

Rouse, in press

The modeling work described above has been directed at describing cognitive workflow in today's Air Operation Center. The project is motivated, however, by a desire to develop a transformational redesign. Once the model of current cognitive workflow is complete, it will be treated as the system to be transformed. A new Brahms model of the transformed system is to be developed and will constitute a prototype that can be explored, evaluated, and then further redesigned. The prototyping problem is essentially one of modeling cognitive workflow in an envisioned system. Further extensive cognitive analysis will be required to develop the vision of what the transformed system should be like.

Enterprise transformation goes beyond Business Process Reengineering in that it starts with transformation of the functional structure of the enterprise (Rouse, 2005; in press). Consistent with Rouse's strategy, my own work over the past several years has leaned heavily on pioneering work by Rasmussen (1986). In particular, Rasmussen's Work Domain Analysis has provided the starting point for my transformational design projects (Lintern, in press; 2002; 2004). Although design for enterprise transformation typically starts with analysis of desired functional structure, subsequent analyses are employed to assess organization and integration of work processes. Structural organization and collaboration become important issues; for example, how to organize and integrate work functions and how to ensure effective human-to-human, machine-to-machine, and human-to-machine communication.



Time	Belief/Fact
21920	belief: (ADOCS.TST_Description = "Standby")
21515	belief: (ADOCS.TST_Description = "Weapons of Mass Destruction")
21455	belief: (CommunicationsNet.TST_Description = "Weapons of Mass Destruction")
20335	belief: (CommunicationsNet.TST_Description = "Standby")
20295	belief: (ADOCS.TST_Description = "Standby")
19890	belief: (ADOCS.TST_Description = "Insurgent Operation")
19830	belief: (CommunicationsNet.TST_Description = "Insurgent Operation")
18710	belief: (CommunicationsNet.TST_Description = "Standby")
18670	belief: (ADOCS.TST_Description = "Standby")
18265	belief: (ADOCS.TST_Description = "Insurgent Operation")
18205	belief: (CommunicationsNet.TST_Description = "Insurgent Operation")
17085	belief: (CommunicationsNet.TST_Description = "Standby")
17045	belief: (ADOCS.TST_Description = "Standby")
16640	belief: (ADOCS.TST_Description = "Insurgent Operation")
16580	belief: (CommunicationsNet.TST_Description = "Insurgent Operation")
15460	belief: (CommunicationsNet.TST_Description = "Standby")
15420	belief: (ADOCS.TST_Description = "Standby")
15015	belief: (ADOCS.TST_Description = "Insurgent Operation")
14955	belief: (CommunicationsNet.TST_Description = "Insurgent Operation")
13835	belief: (CommunicationsNet.TST_Description = "Standby")
13795	belief: (ADOCS.TST_Description = "Standby")
13390	belief: (ADOCS.TST_Description = "High Political Leadership")
13330	belief: (CommunicationsNet.TST_Description = "High Political Leadership")
12210	belief: (CommunicationsNet.TST_Description = "Standby")
12170	belief: (ADOCS.TST_Description = "Standby")
11765	belief: (ADOCS.TST_Description = "Insurgent Operation")
11705	belief: (CommunicationsNet.TST_Description = "Insurgent Operation")
10585	belief: (CommunicationsNet.TST_Description = "Standby")
10545	belief: (ADOCS.TST_Description = "Standby")
10140	belief: (ADOCS.TST_Description = "Insurgent Operation")
10080	belief: (CommunicationsNet.TST_Description = "Insurgent Operation")
8960	belief: (CommunicationsNet.TST_Description = "Standby")
8920	belief: (ADOCS.TST_Description = "Standby")
8515	belief: (ADOCS.TST_Description = "Insurgent Operation")
8455	belief: (CommunicationsNet.TST_Description = "Insurgent Operation")
7335	belief: (CommunicationsNet.TST_Description = "Standby")
7295	belief: (ADOCS.TST_Description = "Standby")
6890	belief: (ADOCS.TST_Description = "Weapons of Mass Destruction")
6830	belief: (CommunicationsNet.TST_Description = "Weapons of Mass Destruction")
5710	belief: (CommunicationsNet.TST_Description = "Standby")
5670	belief: (ADOCS.TST_Description = "Standby")
5265	belief: (ADOCS.TST_Description = "High Political Leadership")
5205	belief: (CommunicationsNet.TST_Description = "High Political Leadership")
4085	belief: (CommunicationsNet.TST_Description = "Standby")
4045	belief: (ADOCS.TST_Description = "Standby")
3640	belief: (ADOCS.TST_Description = "Standby for incoming intelligence on TST")

Figure 5. A chronology of target flow through the communications net and through the Automated Deep Operations Coordination System (ADOCS).

Conclusion And Future Directions

Greater attention is being placed on non-traditional methods of representing and analyzing emergent and adaptive behavior. Methodologies and enabling technologies for quantitatively predicting system behavior are being explored.

INCOSE (2005)

Modeling Issues. An Air Operations Center is a complex socio-technical system that relies for its effectiveness on emergent properties generated by human flexibility and human self-organization. A transformational redesign poses a significant challenge. In general, one of the best experiences for someone who wants to redesign a system is to become immersed in operations of the current system. However, an Air Operations Center is so extensive and so chaotic to the inexperienced eye that the time needed to acquire the requisite experience would be inordinate. The development of a computational prototype is proposed here as a viable alternative. A design team will use that prototype, as design teams have used prototypes in the past, to reflect on and explore potential reconfigurations.

Those who undertake computational modeling are often unclear in their explanations of what they are doing. The above quotation taken from the INCOSE technical vision, offers an illustration. The first sentence of that quotation is well focused; representation and analysis of emergent and adaptive (human) behavior are important issues in the design of socio-technical systems. The second sentence is more troubling because it does not clarify how the prediction is to be accomplished. Most specifically, is it the methodologies and enabling technologies that predict system behavior or is it the systems designers who are now able to predict more effectively given the support provided by those methodologies and enabling technologies?

Is there is an implication in these words that a computer model can predict human behavior and possibly even generate emergent and adaptive behavior? I suggest that such a claim is in the realm of science fiction. Computational models can do many wonderful things but they do not think. The support offered by a computational model in contrast to a physical prototype differs in magnitude but not in kind. The concern I raise is specifically the reason for the earlier discussion about the difference between physical modeling and human performance modeling. The aim of an energy efficiency model can be to predict how energy-efficient a home might be. In contrast, we do not yet have the fundamental knowledge that will enable us to predict human performance in anything other than trivial circumstances. A Brahms model of cognitive workflow in an Air Operations Center does not predict in anything other than a peripheral sense and it does not generate emergent or adaptive behavior.

On the other hand, a Brahms model can describe emergent and adaptive behavior that might be observed by an analyst. Where that emergent and adaptive behavior is important for the design effort, the analyst must summarize it and describe it for other members of the design team. A Brahms model is a convenient and flexible method for providing that description. The model can also be used to instantiate the predictions of members of the design team in a manner that can engage interdisciplinary discussion about viability and feasibility. By examination of process flows in the Brahms model, members of the design team might be able to anticipate what will happen under different circumstances in operational system. Those predictions will always be tentative and would need to be tested more rigorously in a physical system with experienced operational staff. In general, I envisage my Brahms modeling efforts as a prelude to Human-in-the-Loop evaluation.

Motivation for Computational Modeling. The interest in a computational model to describe cognitive processes was motivated by two informal observations. The first is that representation of cognitive demands for a complex socio-technical system poses a significant challenge. Static diagrams work well for simple or tutorial systems but quickly become so detailed and dense for complex, operational systems that they make sense only to the analyst who constructs them.

The second observation relates to the allure that computational models have for a design and acquisition community in which the techno-centric worldview has the status of a cultural imperative. I take the optimistic view that many already recognize the problems we face in the design and acquisition of complex socio-technical systems and that, given recognition of the need, a plausible and evocative alternative can generate and maintain cultural change.

Brahms offers a potential solution to the challenge identified by the first of these observations while providing an answer to a significant design problem in a form that is likely to have considerable appeal to many who might otherwise take little notice.

Brahms as a collaborative, exploratory tool. Lying behind the work described here is the view that design is fundamentally a collaborative process. For a complex socio-technical system such as an Air Operations Center, that collaboration will necessarily be interdisciplinary. Specifically, this will require strong collaboration between cognitive engineers, systems engineers, software engineers and military operational experts. A multi-disciplinary team in which members of the various disciplines and areas of expertise work somewhat independently will not do. The need is for the exploratory engagement and dialectic to be interactive, ongoing and mindful regarding the essential design issues.

Today’s most common form of collaborative technical and scientific echange, the formal Power Point presentation, is entirely ineffective as a design interaction. An interdisciplinary team needs a design artifact that they can examine, reconfigure and argue about. In some environments, that will be a physical prototype, but the Air Operations Center is too complex for that. The Brahms environment is presented here as a convenient and flexible prototyping tool to aid a redesign effort for this large-scale socio-technical system.

As it now stands, the Brahms simulation environment is not entirely suitable for this design mission. It most significant advantage is that the simulation engine is compatible to a relevant theory of cognition and offers most of the features needed to describe agent performance and agent-to-agent interactions in a complex socio-technical system. On the other hand, the static and relatively constrained output representations are unlikely to promote dynamic, exploratory interaction by diverse members of a design team. This is an issue I continue to explore in a currently funded project that is aimed at developing evocative and informative representational forms for cognitive demands. A currently unfunded work plan to modify the output capabilities of Brahms has been developed.

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