Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
International Journal of Industrial Ergonomics 36 (2006) 409–422
International Journal of INDUSTRIAL ERGONOMICS
www.elsevier.com/locate/ergon

A functional workspace for military analysis of insurgent operations

Gavan Lintern

General Dynamics-Advanced Information Engineering Systems, 5200 Springfield Pike, Suite 200, Dayton, OH 45431-1289, USA

Available online 13 March 2006

Abstract

Information overload has become a critical challenge within military operations. However, the problem is not so much one of too much information but of abundant information that is poorly organized and poorly represented. Here I report the development of a prototype functional workspace to resolve this issue. Development proceeded through a design sequence of cognitive analysis, knowledge representation and workspace design. The cognitive analysis focused on the specific information needed for analysis of insurgency operations. Abstraction–Decomposition matrices from the framework of Cognitive Work Analysis were used as design artifacts to represent knowledge acquired during the cognitive analysis. Additional design guidance related to workspace layout and format was drawn from operational and scientific literature. The workspace was structured in terms of dimensions of functional abstraction and functional decomposition; dimensions that are thought to characterize the fundamental structure of cognitive work. In this paper, I describe the analysis and how its products were integrated with insights drawn from operational and scientific literature to develop the prototype workspace.

Relevance to industry

Visualization is often proposed as a solution to the challenges of cognitively intensive, information-rich work. This paper outlines principles and analytic procedures that can be used to develop a visualization for cognitive work.

Keywords: Cognitive engineering; Functional design; Workspace visualization; Information management; Military intelligence planning

1. Information management: the contemporary problem

Information management has emerged as a significant contemporary challenge in modern warfare. The advantage now goes not to those with the more potent weaponry but to those with the more effective information system. Military analysts can access a huge amount of information from multiple and diverse sources. That information is now available in different forms and at different levels of abstraction and, when it is about current status and progress of events, it has become available with unprecedented speed. Nevertheless, this information is poorly organized. It is available from diverse sources and in fragments, which leaves an analyst with the challenge of searching the information space to find, distinguish, summarize, integrate and understand the meaningful elements that can make a difference. That is both an onerous and a difficult task. In a high-tempo, high-stress environment it will often be an impossible one.

Information must be indexed and then displayed so that users can find their way through it. Libraries have traditionally indexed books with formal cataloging systems. More recently, keyword searches have become popular for electronically stored information. Another approach is to structure information in a manner that reflects the structure of the cognitive work so that information is assimilated readily and so that there are natural transitions between elements. The emphasis is on functional information that supports purposeful (functional) action. Because of its allegiance to the principles of Ecological Psychology, this latter design strategy has been characterized as Ecological Interface Design (Vicente and Rasmussen (1992) although following Lintern et al. (1999), Functional Interface Design is preferred in this paper as a more operationally relevant term.

A central assumption of Ecological Psychology is that the functional needs of an organism necessarily reciprocate the functional structure of that organism's natural world

E-mail address: glintern@earthlink.net.

0169-8141/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.ergon.2006.01.005

(Gibson, 1979; Reed and Jones, 1982). In accordance with that assumption, Functional Interface Design is aimed at developing a virtual world that reciprocates the structure of the cognitive work. Success of this endeavor hinges on selection of a suitable dimensional structure; an unsuitable structure is unlikely to be any better than no structure at all. Rasmussen et al. (1994) and Vicente (1999) argue that experts solve problems by navigating through a dimensional space of functional abstraction and functional decomposition. Rasmussen et al. (1994) and Vicente (1999) have extended their claim to cognitive work in general. Although their evidence is meager, they appear to be the only researchers who have addressed the issue of the dimensional structure of cognitive work and so, by default, their view was incorporated as a guiding assumption for the design work reported here.

A functional workspace is one that reveals the constraints on work. The key tenets of Ecological Psychology relevant to workspace design are:

- human action is constrained by the work domain,
- interfaces are mediated environments that can reveal the work constraints,
- information can be depicted in a manner that supports direct perception of those constraints.

Functional Interface Design is the process of analyzing the work domain to identify its constraints and then developing perceptual forms that reveal those constraints directly in the workspace.

2. Design strategy

The design strategy for building a functional workspace has four distinct stages; knowledge acquisition, knowledge representation, design specification and prototype development. Where innovation is required, considerable iteration will be necessary, as for example, in the process of spiral development.

One of the more challenging issues for this design strategy is the transition from analytic products to design specifications. Specifications for different system properties can be derived from different phases of Cognitive Work Analysis as suggested by Vicente (1999, p. 115) and representational forms can be drawn from the human factors display literature and from work domain publications as recommended by Rasmussen et al. (1994). This process leads to specifications of the following types:

- Information Requirements—the information that should be displayed;
- Information Layout and Workspace Navigation—the relational organization of information and the navigation capabilities needed to search for, integrate or associate different information elements;
- Action on the Work Domain—the form, content and magnitude of actions and transactions by and between entities; and
- Information Representation—the representational forms that permit workers to perceive meaning rapidly.

The knowledge acquisition and knowledge representation stages for the work reported here commenced with Work Domain Analysis and development of Abstraction–Decomposition matrices as laid out explicitly in Lintern (2005), following the guidance of Vicente (1999).

Work Domain Analysis identifies the functional structure of a socio-technical system, starting with object descriptions at the lowest level, with mappings to specific functions, general functions, and specifications of system purpose at higher levels. It helps to identify functional properties that result from design intent, those that are discovered by operators and those that are generated by interactions with the environment whether desirable or undesirable. A major contribution of Work Domain Analysis is identification of means-end relationships between functions at different levels of abstraction. A means-end relation reveals the functions at one level that must be used for satisfaction of a function at a higher level. In most cases, a constellation of functions at the lower level will be required to satisfy any function at a higher level.

The product of Work Domain Analysis (e.g., the way the acquired knowledge is represented) is a two-dimensional Abstraction–Decomposition matrix that distributes functions across levels of abstraction (object descriptions, physical functions, purpose related functions, values and system purposes) and across degrees of decomposition. By convention, abstraction is represented on the vertical dimension and decomposition on the horizontal dimension. Many treatments of the abstraction dimension use general terms for the five levels (e.g., System Purpose, Values & Priorities, Purpose-Related Functions, Physical Functions, and Physical Resources). For this paper, I have substituted operationally specific but compatible terms (System Mission, Operational Principles & Values, General Mission Functions, Technical Functions & Contextual Effects, and Physical Resources & Constraints).

An Abstraction–Decomposition matrix is an activity-independent description of a work domain. The distinction between activity-independence and activity-dependence was considered fundamental to this work. From the ecological perspective, an activity-independent structural analysis is foundational and therefore demands extensive effort. However, activity-dependent descriptions are also essential and these are typically developed in the other four phases of Cognitive Work Analysis. Within this project (as with many others in which Cognitive Work Analysis is used) relatively few resources remained for the phases beyond Work Domain Analysis. Where resources are limited, narratives of typical scenarios can provide a useful, albeit limited analysis of activity (tasks to be accomplished, useful strategies, worker coordination, and levels of cognitive control). Narratives are limited as an information source for workspace design because each one constitutes only one of the many possible trajectories through a

workspace (and one that may not even be critical) although they can nevertheless serve as a waypoint in the design of an early prototype.

3. Work domain analysis of insurgency operations

> *Insurgency*: rising up against established authority; rebellious; a revolt or rebellion not well enough organized to be recognized in international law
> *Webster's new world dictionary of the American language*

The purpose of the proposed workspace is to help a military analyst understand the structure and processes of an insurgency and also how Allied resources and processes can be used to counter an insurgency. The analysis started with a discussion with two subject matter experts and then proceeded through a review of documentation (interspersed with further discussions with the subject matter experts) to converge on Abstraction–Decomposition matrices for both insurgency and counter-insurgency (the counter-insurgency matrices, not shown in this paper, were similar in structure and content to the insurgency matrices although the specific physical devices and their capabilities differed considerably). One subject matter expert developed a scenario narrative of an insurgent operation; planning for an ambush of a security convoy. This further supported development of the insurgency matrix. However, the bulk of that narrative described activity rather than functional structure. Those activity elements were used to annotate the Abstraction–Decomposition matrix in the manner described later in this paper.

Decompositions were taken to the level suggested by the subject matter experts. Subsequently, many functions were decomposed to more detailed levels than others. In practice, Work Domain Analysis is typically an iterative developmental process of adding functions and rationalizing levels of decomposition. It is to be anticipated that the levels of decomposition will become more consistent as those iterations continue in this project, although it is unlikely that even the final version of the analysis will see all functions decomposed to precisely the same level. In the matrices that follow, decompositions are shown as successively nested within the decomposed function (e.g., Fig. 1, row 3).

3.1. System Mission

The mission of an insurgent organization is to generate political instability, progressing to the next phase of political influence and eventually, ascendancy and institutionalization of its own political agenda (Fig. 1, row 1). This mission will be expressed by the leaders of the insurgency but interpreted by local commanders to be

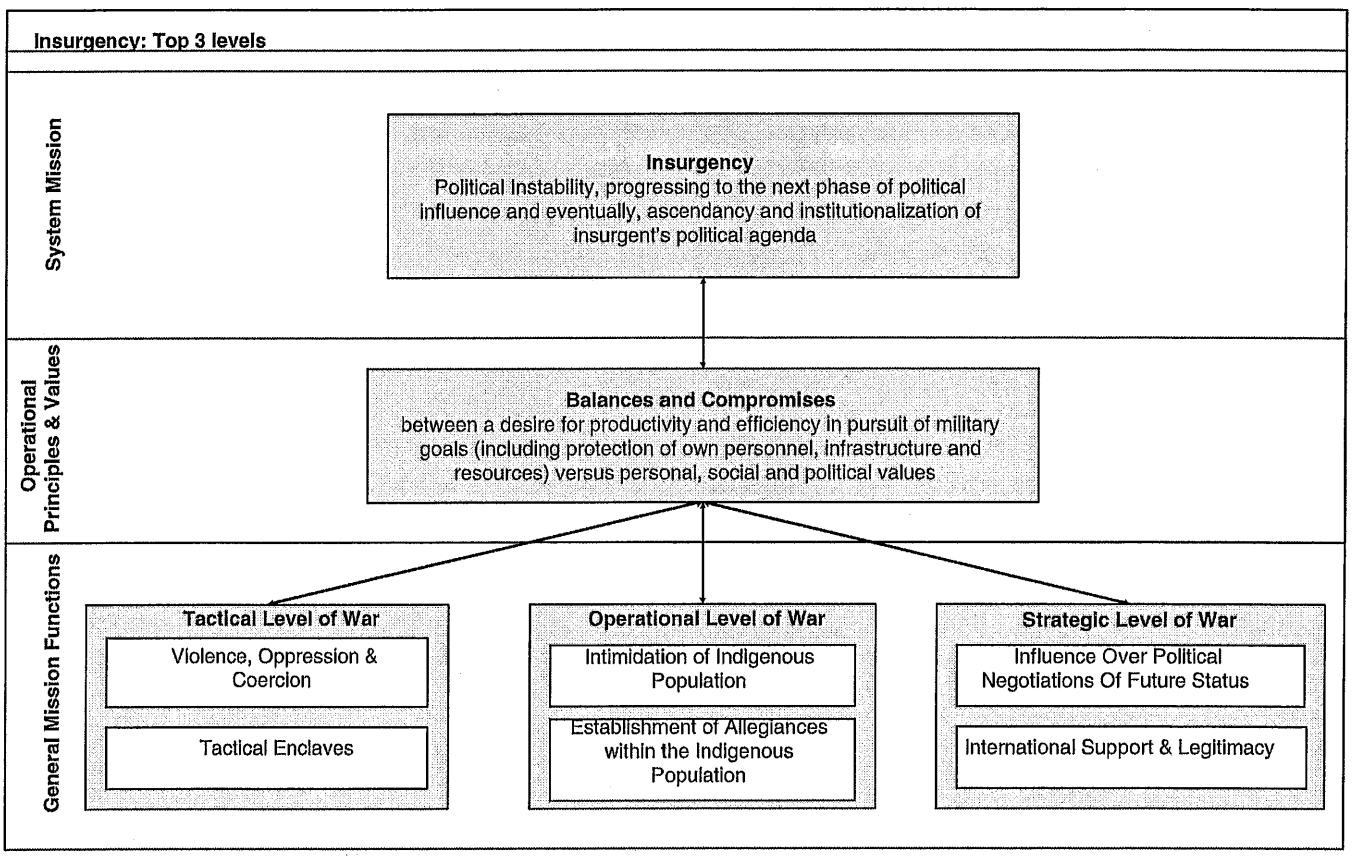

Fig. 1. Abstraction–Decomposition matrix (upper 3 levels only) derived from an analysis of insurgency resources and purposes.

adapted to the specifics of the conflict environment within which they are operating.

3.2. Operational Principles & Values

As shown in Fig. 1 (row 2), Operational Principles & Values emphasize productivity and efficiency (e.g., timely establishment of tactical and strategic advantage together with protection of own personnel, infrastructure and resources). Some of the personal, social and political values that constrain operations will be related to the ideology and dogma of the insurgency leadership and the supporting elite such as a desire for vengeance and opportunities for exploitation of international law and conduct balanced against the need for international legitimacy.

3.3. General Mission Functions

A classification system described by Beagle (2000) was used to organize functions at the General Mission level (Fig. 1, row 3). Beagle distinguishes three levels of war and identifies the types of effects at which each of these levels might be directed:

- The *tactical* level is directed at the adversary's ability to wage war; it addresses battlefield engagement at the unit level and below and focuses on combat maneuvering with emphasis at a local scale on limited-duration physical effects that are immediate but with limited scope of influence
- The *operational* level is directed at the adversary's ability to sustain war; it addresses planning and conduct of campaigns and major operations within a theater with emphasis on moderate-duration systemic effects (both economic and social)
- The *strategic* level is directed at the adversary's ability or will to sustain war; it addresses military and security objectives and focuses on vital centers (military, political, economic, or social) with emphasis on long-duration systemic and psychological effects (ability or will) that may unfold non-linearly (no apparent effect and possibly even some improvement followed by precipitous collapse) but with considerable (potentially, war ending) influence

For pragmatic reasons associated with project time and resource constraints, the remainder of the analysis was restricted to Violence, Oppression and Coercion at the Tactical Level of War, with an emphasis on offensive and defensive operations. Decompositions of that function are shown in Fig. 2, (row 1). While these are the most obvious functions of an insurgent force, no insurgency can flourish in the absence of supportive social conditions such as poverty and disenfranchisement of the indigenous population and ethnic and national affiliations. In addition, functions such as charismatic leadership and insurgency doctrine will come into play. These other functions, although identified in the analysis, are not noted in any further detail in this paper in order to limit the complexity of the figures and the discussion.

3.4. Technical Functions & Contextual Effects

Technical Functions & Contextual Effects are identified in Fig. 2 (row 3). A decomposition of the Technical Functions & Contextual Effects that impact the General Mission Function of Violence, Oppression and Coercion is shown in Fig. 3.

3.5. Physical Resources & Constraints

The insurgent hardware, personnel and infrastructure are identified in Fig. 2 (row 3). There are some physical resources that one might not anticipate from consideration of conventional warfare. Fake documents, international mail systems, wall cavities (as hiding places) and domestic hardware (garage door openers as remote triggering devices) offer resources for an insurgency with limited access to military hardware and that must operate covertly. A decomposition of this level is shown in Fig. 4.

4. Activity analysis of insurgency operations

In the standard framework for Cognitive Work Analysis, control tasks, strategies, social organization, and levels of cognitive control are examined in separate analytic phases. In this project, with its limited resources, those four dimensions of activity were assessed within a single scenario narrative. For that narrative, any activity involving a function represented in the Abstraction–Decomposition matrix was associated with that function. An annotation in the form of a callout superimposed on the Abstraction–Decomposition matrix and pointing to the relevant functional node was used to represent an activity-function association (Figs. 5–8). At the lower three levels of the matrix in particular, these callouts reveal how the insurgents organize the ambush, how they execute it, how they extract themselves from the ambush site, and what resources they employ. Scenario references to specific ethnic and religious groups were edited out of the activity callouts.

5. A prototype workspace

The vision for a workspace to support a military insurgency analyst is one of a fully integrated and comprehensive information system that relies heavily on visualization and employs many computerized means of transforming, selecting, highlighting and associating information. It will employ icon libraries (some possibly auditory, e.g. Leung et al., 1997), work templates, drag-and-drop functionality, selection by mouse click, association by linking with mouse action, interrogation

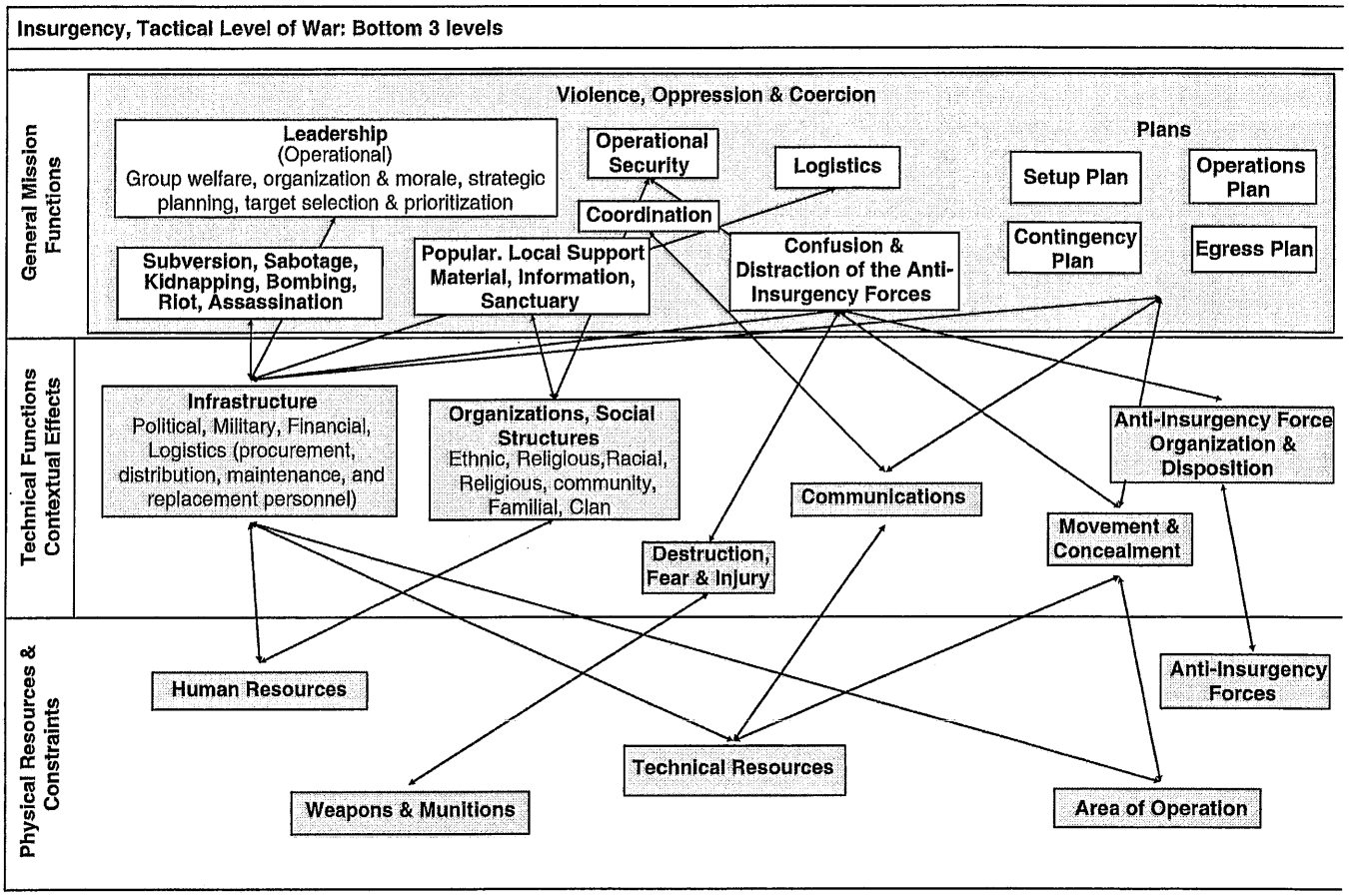

Fig. 2. Abstraction–Decomposition matrix (lower 3 levels only) derived from an analysis of insurgency resources and purposes showing a decomposition of Violence, Oppression and Coercion (a General Mission Function) at the Tactical Level of War.

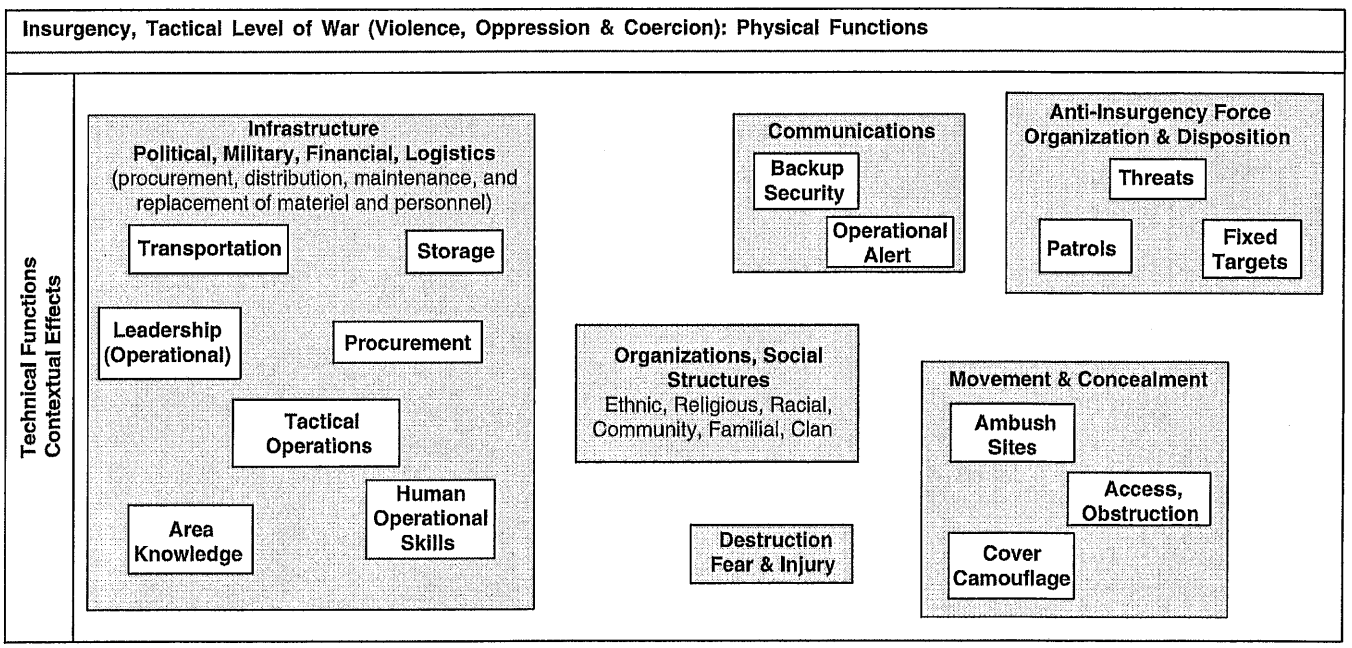

Fig. 3. A decomposition of the Technical Functions & Contextual Effects that support the General Mission Function of Violence, Oppression and Coercion at the Tactical Level of War.

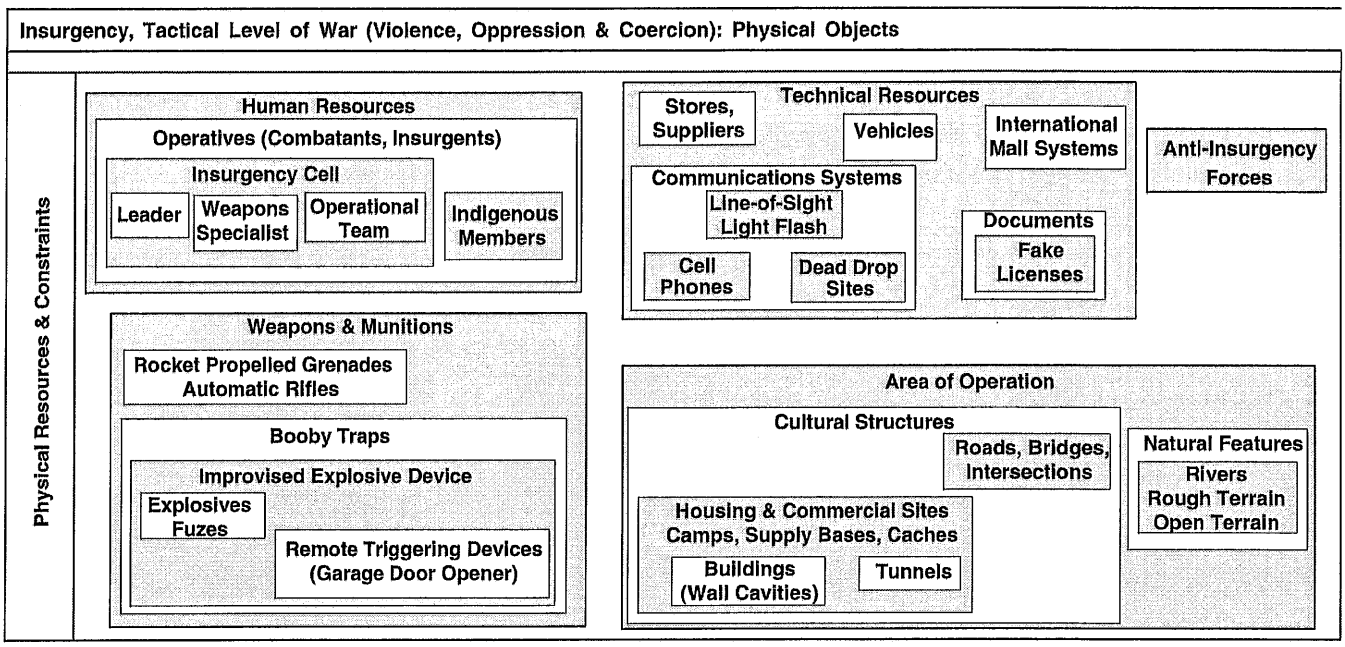

Fig. 4. A decomposition of the Physical Resources & Constraints that support the Purpose-Related Function (via Technical Functions and Contextual Effects) of Violence, Oppression and Coercion at the Tactical Level of War.

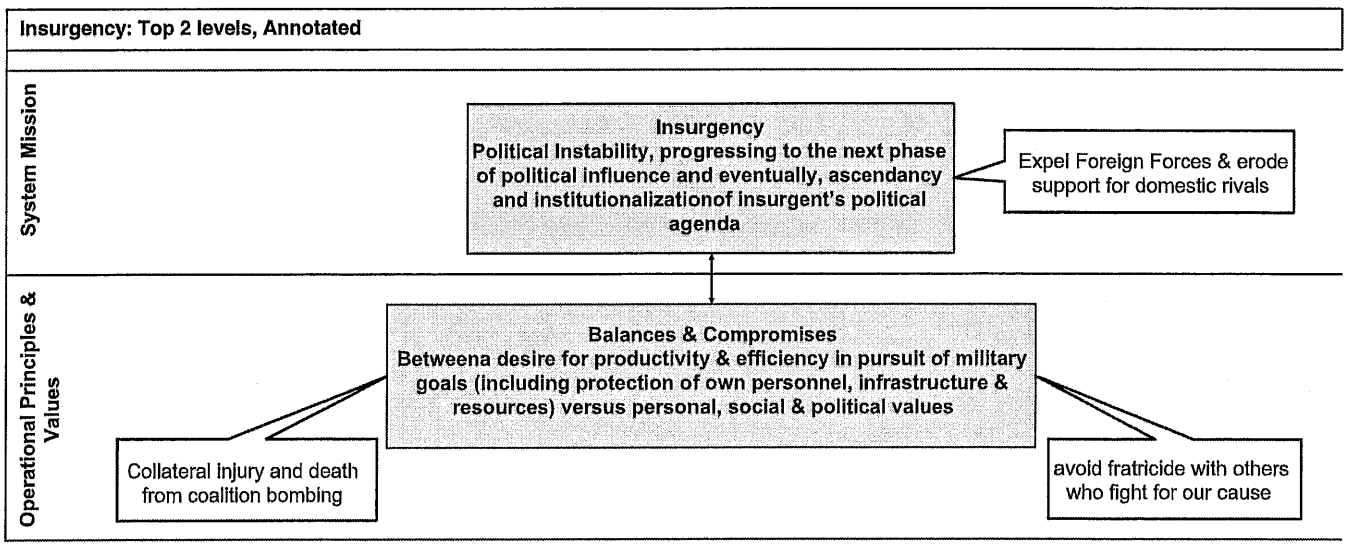

Fig. 5. Abstraction–Decomposition matrix (upper two levels only) with an activity overlay derived from an insurgency narrative.

of concepts to bring up more detail or lower-level abstractions, and convenient modeling tools to test outcomes of proposed actions.

Essential information will be readily accessible and presented in succinct and meaningful forms. There will be summaries of contextually relevant information and readily apparent signs to guide access to it. Evocative perceptual forms will be used for skill- and rule-based analysis and the verbal information required for support of knowledge-based analysis will be summarized and highlighted so that the analyst can converge readily on essential meaning as it relates to the current issue.

In this section, I outline how the results of the cognitive analysis reported above were integrated with selected design concepts to advance this vision.

5.1. Workspace architecture

The workspace architecture used here follows the single-window, multi-panel format of a functional interface developed for planning and problem solving at the flight engineer's station of a Hercules C-130 aircraft (Dinadis and Vicente, 1999). Linegang and Lintern (2003), Lintern (2002) and Lintern, et al. (2002) have subsequently used

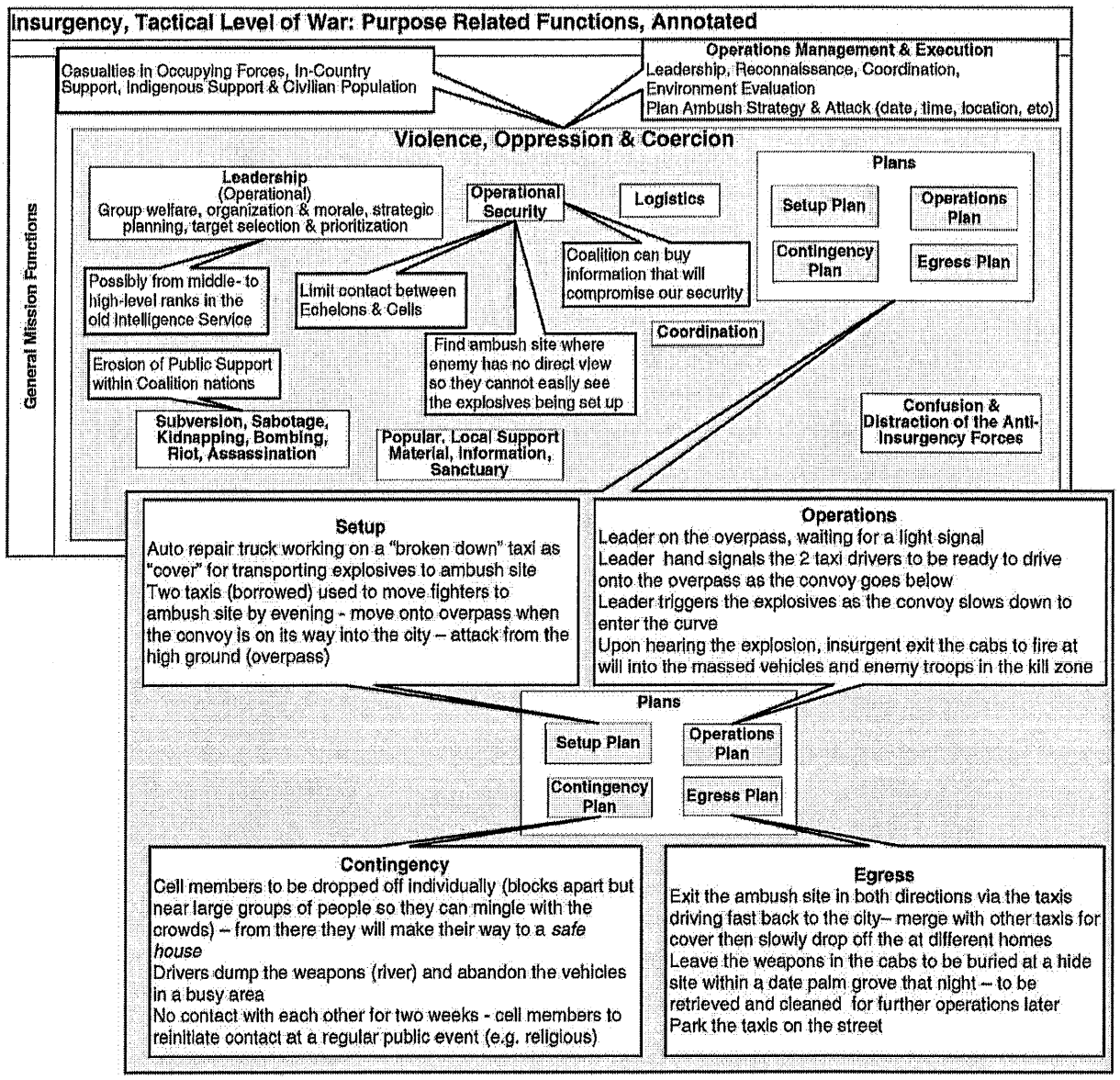

Fig. 6. General Mission Functions overlaid with activity elements derived from an insurgency narrative.

this form of structure for military command and planning workspaces. The multi-panel format is shown in Fig. 9.

5.2. *Workspace organization*

A planning workspace must support the interplay between top-down and bottom-up exploration that characterizes the cognitive activity associated with military analysis. It should therefore present a global structure while it provides access to detail. To comply with the assumption that experts perform cognitive work by navigating through a dimensional space of functional abstraction and functional decomposition, the organizational form should reflect the structure (although not necessarily the spatial layout) of the Abstraction–Decomposition matrix.

In development of design specifications, each node in the Abstraction–Decomposition matrix identifies an information requirement that should be represented in the workspace. Functional allocations were guided by previous work (Lintern, 2002; Lintern, et al., 2002). It was also guided by the work of Burns (2000), which suggests that temporal proximity aids navigation along decomposition links while spatial proximity aids navigation along means-end links. The implication of Burn's work is that a different level of abstraction should be made available by replacing the view of the original function in the same panel while the decomposition of a specific function should be made available simultaneously in a nearby panel.

System Mission was allocated to the top left panel and Operational Principles & Values to the top right panel. As with previous projects (Lintern, 2002; Lintern et al., 2002),

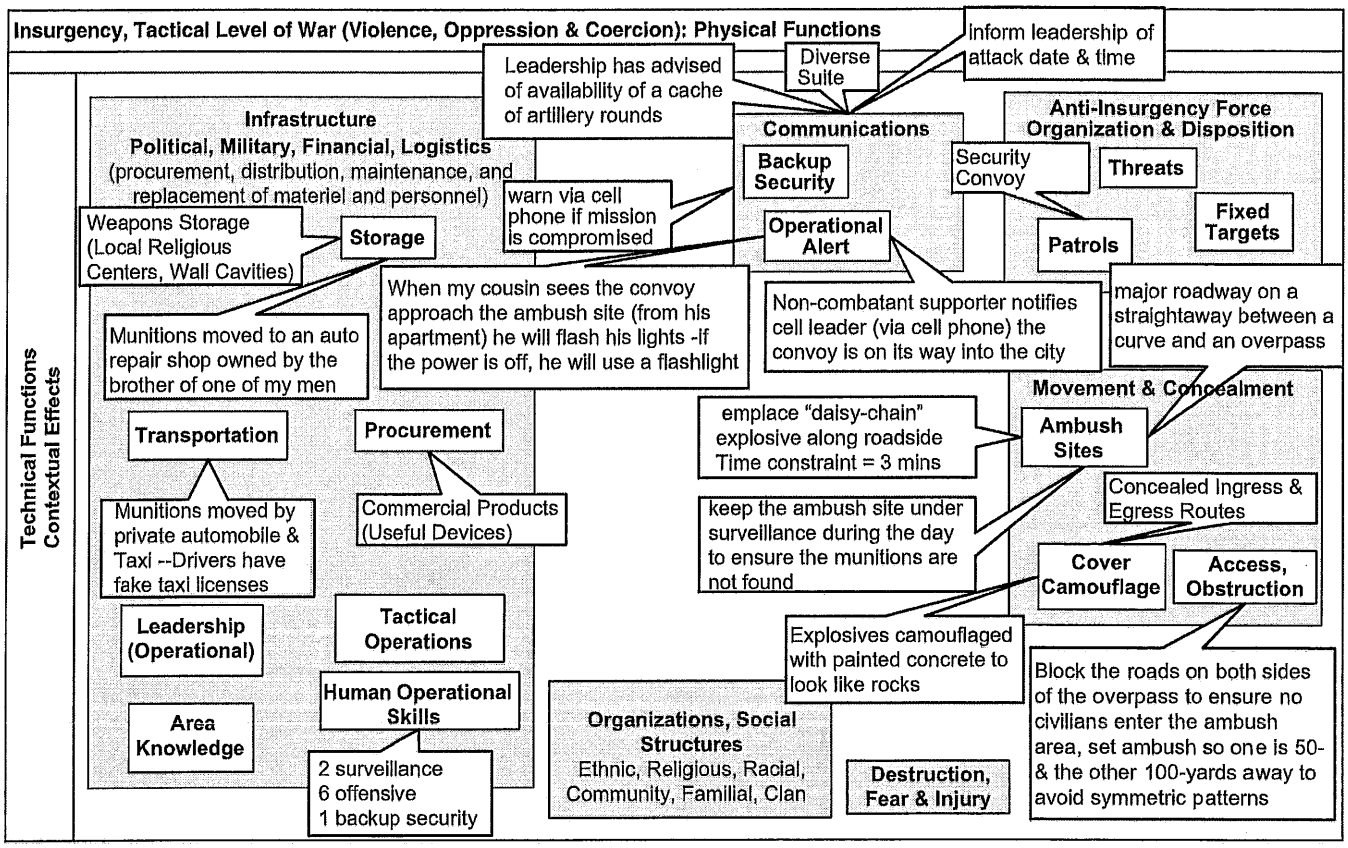

Fig. 7. Technical Functions & Contextual Effects overlaid with activity elements derived from an insurgency narrative.

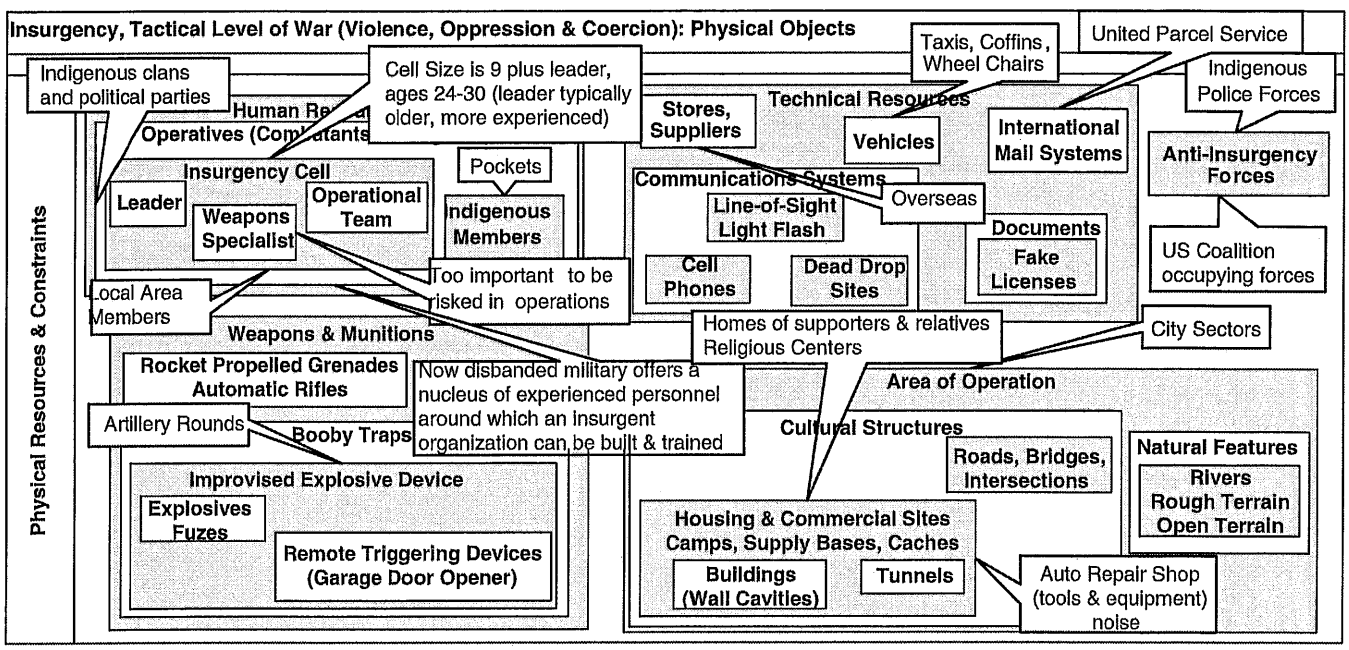

Fig. 8. Physical Resources & Constraints overlaid with activity elements derived from an insurgency narrative.

the subject matter experts for this project were adamant that the workspace should contain a geospatial situation display. The central panel was allocated to that requirement so that the essential resources for support of activity within the geospatial area could be distributed around its periphery as is consistent with the Focus-Periphery

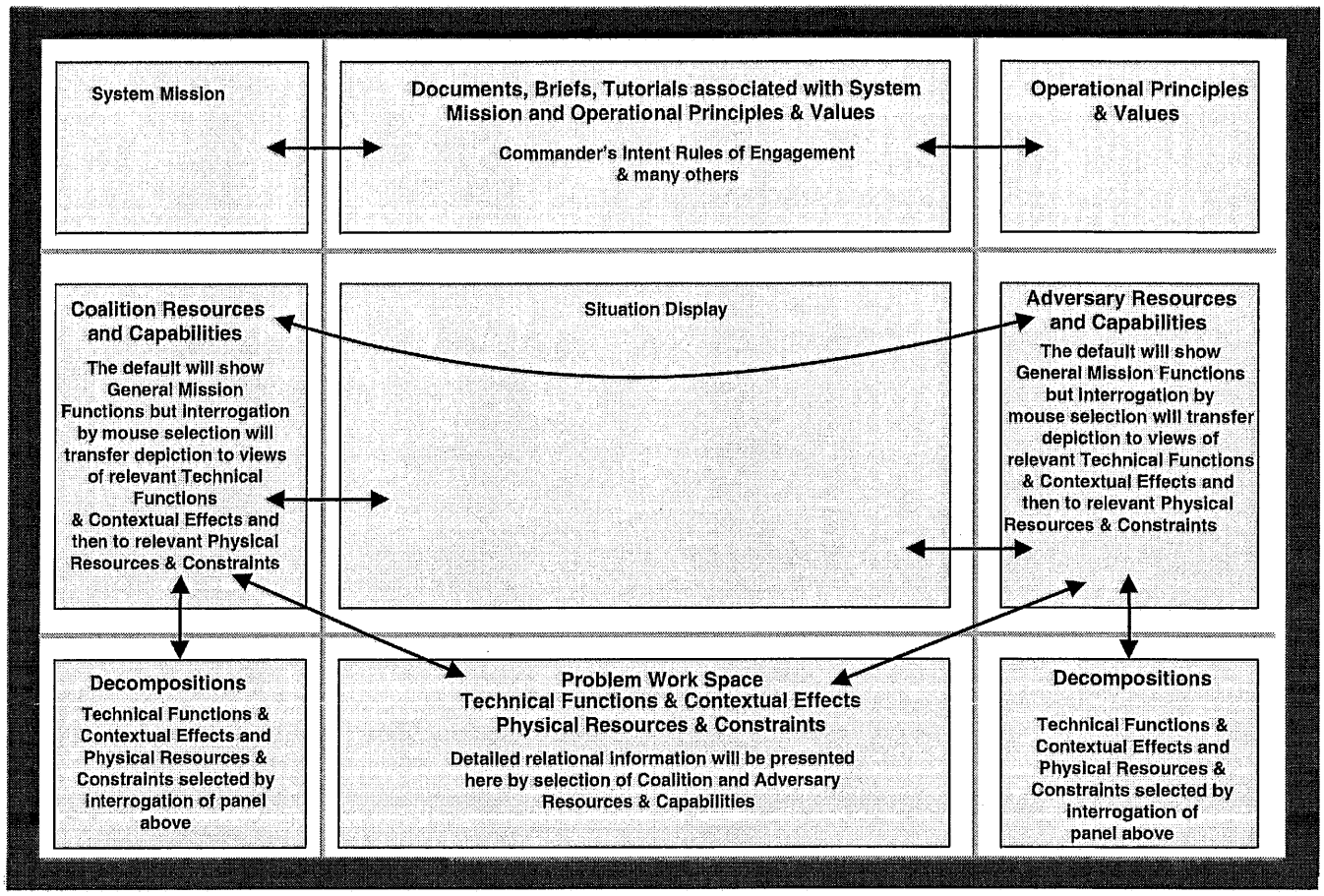

Fig. 9. A distribution of functions within the multi-panel format as derived from Abstraction–Decomposition matrices, together with the associations and linkages between various panels as derived from means-end and decomposition links and activity narratives.

Organization Principle (Eggleston and Whitaker, 2002). Allied Resources at the General Mission Function level were allocated to the left-center panel and Adversary Resources at the General Mission Function level to the right-center panel.

The top-center and bottom-center panels are workspaces in which the analyst will explore details and relationships for System Mission and for Operational Principles & Values (upper center) and Technical Functions & Contextual Effects and Physical Resources & Constraints (lower center).

5.3. *Representational forms*

Perceptual forms for a functional workspace are derived not from analytic products but from research, design and operational literature. Some ideas for perceptual forms were derived from human factors research on evaluation of displays and perceptual forms. Other sources consulted (see Table 1) were Rasmussen (1998), who has outlined a typology of graphic display formats (library of perceptual forms) for representation of states, relationships and constraints at different levels of abstraction, Dinadis and Vicente (1999) and Pejtersen (1992). Since this work was completed, Burns and Hajdukiewicz (2004) have developed a visual thesaurus of forms for representation of work domain constraints that will aid further development of this workspace.

Fig. 10 depicts an example state of the prototype workspace. Most of the pictorial forms have been taken from military operational documents but the top-left and top-right panels contain a configural element, the polar star, as used by Dinadis and Vicente (1999) in a functional interface. Some comments by the subject matter experts suggested the value of historical information about operational parameters and details of how they are measured. In a polar star, a description of how a parameter is measured might be accessed by selection at the end of a radial and historical information about that parameter might be accessed by selection elsewhere on the radial. The identification and measurement of important operational parameters was not assessed systematically within this project and must be the focus of further cognitive analysis.

5.4. *Workspace description*

The top left panel of Fig. 10 offers a configural representation of System Mission in the form of an

Table 1
A typology of display formats for different levels of abstraction, adapted primarily from Rasmussen (1998) but also with reference to Dinadis and Vicente (1999) and to Pejtersen (1992)

Types of functional properties	Representation requirements	Formats
System Mission	Overview	Configural displays Check-off tables Limit-constraint diagrams
Operational Principles Operational Values	Flow Mass Value Balance Accumulation Dispersion	Configural displays of balances & Relationships between functions & states Limit envelopes & containers Visual perspective Alphanumerics
General Mission Functions	Relations Intended states Trajectories Offensive capability Defensive capability	Configural displays Constraint boundaries Containers Threat & lethality shadows Guides Predictor elements & envelopes Symbolic diagrams Target lists Priority indicators Visual perspective Fields of action Alphanumerics
Technical Functions Contextual Effects	Status of process variables with reference to target states and to limits of acceptable operation	
Physical Resources Physical Constraints	Topography of the work system	Object representations Icons, symbols, signs Mimic diagrams Pictorial representations Flow maps Ingress & Egress routes Locations

eight-sided Polar Star normalized to measures of how well the system purpose is being satisfied. For the insurgency purpose identified in Fig. 5, measures of political stability might be derived from statistics on industrial production, industrial investment, school attendance and domestic security. Measures of perceived legitimacy (both national and international) of the insurgent's political agenda might also be useful. The narrative suggests that measures of support for domestic rivals and for the presence within the country of foreign forces would be relevant.

The top right panel of Fig. 10 has a Polar Star that depicts normalized parameters associated with Operational Principles & Values. Ratios of successful to unsuccessful insurgent operations and measures of impact for the successful ones may offer useful measures. The narrative suggests the significance of parameters associated with insurgent success in protection of own personnel, infrastructure and resources. The narrative further indicates that measures of collateral injury and death from coalition operations should be monitored because they strengthen insurgency recruitment.

The top-center panel provides access to documents related to System Mission and to Operational Principles & Values. The cognitive analysis needed to determine the content and style of such documents has not yet been done but these resources are envisioned as succinct summaries of no more than a page or two organized to be relevant to a general context selected via the two-by-three matrix of buttons to the left. The dimensions of this matrix are currently conceptualized as Type of Effect (Physical, Systemic, Psychological) by Level of War (Tactical, Operational, Strategic) as is consistent with the results of

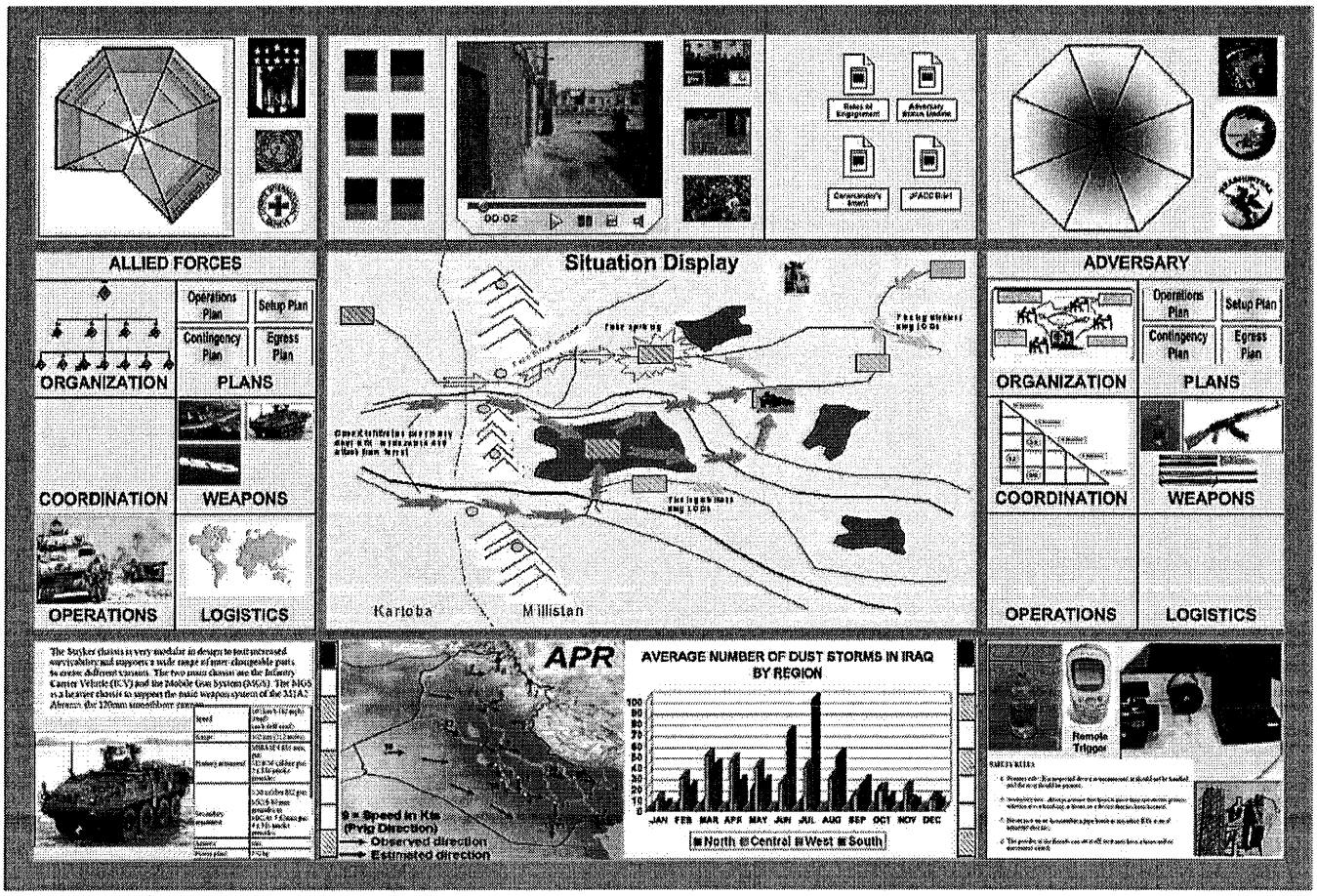

Fig. 10. A depiction of an information–action workspace for Insurgency Analysis (the illegible text in this figure was not derived from the analysis but is presented to illustrate how text and graphics might both be useful—this figure is intended to be instantiated as the surface of a large information table on which text of this relative size would be legible).

the analysis. The narrative made no reference to insurgent documents on this topic but there are presumably some accounts and summaries that could be made available within this panel.

Details of Technical Functions & Contextual Effects will be accessed and brought into the foreground by mouse interrogation of the relevant General Mission Functions. Details of Physical Resources & Constraints will, in turn, be accessed and brought into the foreground by interrogation of the relevant Technical Functions & Contextual Effects.

To illustrate, the analyst may wish to explore how an insurgent organization is maintaining coordination. The Coordination graphic in the panel for adversary resources (General Mission Function) shows a coordination matrix that depicts the frequency and magnitude of transactions between known members of the insurgency. Interrogation of the matrix could reveal Technical Functions that support coordination, primarily communication functions. As shown in Fig. 3, some of those communication functions relate to backup security and to operational alerts. The Physical Resource level reveals that drop sites, cell phones and line-of-site light flashes are used (Fig. 4).

The narrative reveals different types of message content at the Technical Function level linked to specific means of communication at the Physical Resource level. By interrogation of a Plans graphic at the General Mission Function level (Adversary resources panel), the analyst would again be taken via one path to components of the communication node at the Technical Function level and would then be able to assess how development and execution of plans was facilitated by the different modes of communication.

The Situation Display in the center panel is the primary workspace in which planners or commanders might *drag-and-drop* items from the Allied and Adversary resources panels to the left and right (respectively) and might relocate those resources (as in the old style *sand table*) or interrogate their functional and physical properties. That interrogation could activate more detailed views in the bottom left or right panels.

Information relevant to action within the Situation Display might be assembled in the Problem Work Space (bottom-center panel) to explore possibilities for Course of Action (both Allied and Adversary). One of the recurring themes coming out of the analysis was the concern of

planners with relationships between Allied and Adversary capabilities and with the effects of environment on operations. The Problem Work Space (bottom-center) of Fig. 10 is based on a capsule scenario in which one of the subject matter experts expressed concern with effects of dust storms on operations. Further exploration would link both allied and adversary capabilities to the information assembled in this panel to examine possible impact of those dust storms on current or potential operations. Tabs to the left and the right of this panel aid selection of information related to different issues that could impact operations.

More detailed information might be brought into view by overlaying it temporarily on the primary workspace. To illustrate, the Polar Star for System Mission shows a problem with one parameter. A depiction of a time history (Fig. 11) for that variable might be brought into view by clicking on the shortened spoke. This particular format, developed by Tufte (1997), shows status 6 months in the past, the previous month, and daily over the last several days, with bars showing the limits of normal or desirable range. The goal is to remove the problem of understanding what is happening with this variable so that the analyst can move quickly into the cognitive problem-solving mode of ascertaining why it is happening and what to do about it (Tufte, 2003).

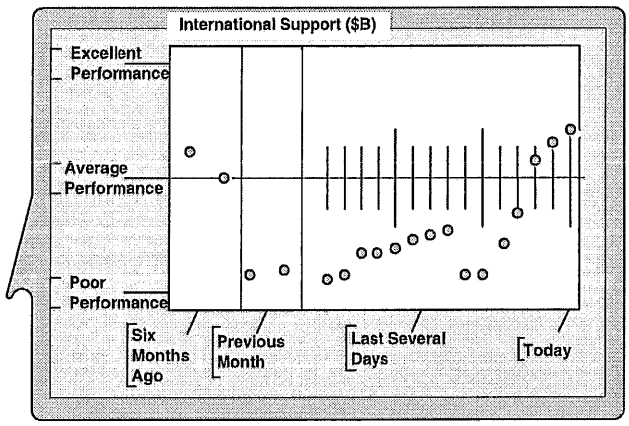

Fig. 11. A time history of international investment support (dummy data) following a pattern graphical style developed by Tufte (1997).

Interrogation of an active resource in the bottom left panel might bring up more information on that weapons system, such as a graphic depiction of weather effects on the targeting performance of that system. Selection of a document icon in the top-center panel might open a summary related to Operational Principles & Values, such as a summary of Rules of Engagement. The subject matter experts had noted that planners would be familiar with the Rules of Engagement but would occasionally need to check or confirm subtle specifics and may have to do so under time pressure. That forces a scan of a large document; a particularly onerous requirement in a time-stressed situation. The pop-up summary (Fig. 12), taken from United States Marine Corps (1998), is intended to resolve that problem by having a succinct and pertinent summary at hand. Layers of detail might be provided, eventually leading to the full document.

5.5. *Workspace navigation*

The associations between functions within the workspace are determined on the basis of the decomposition links and means-end links identified by the Work Domain Analysis and the organization and flow of work processes identified by activity analyses. Following the implications drawn from Burns (2000), information about the lower two

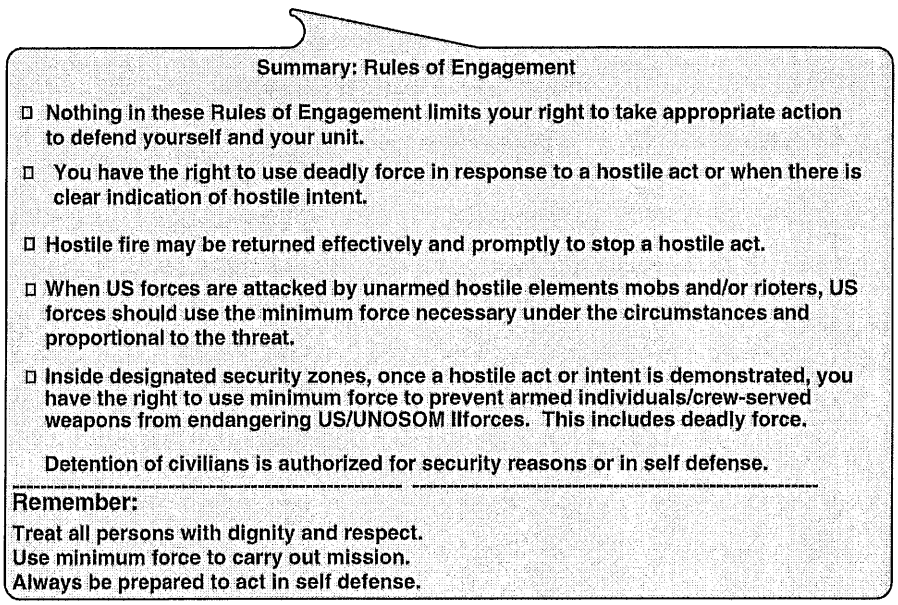

Fig. 12. A brief summary of critical issues taken from a more extensive operational document, in this case Rules of Engagement (adapted from United States Marine Corps, 1998).

levels of abstraction will replace the default views in the resource panels by interrogation of resource-panel information already in view and this interrogation will simultaneously bring up decomposition views of the selected resource.

As an example of the manner in which means-end and decomposition links are used to determine associations between panels, note from Fig. 2 that the General Mission Functions of Operational Security and Plans are means-end linked to the Technical Function of Movement and Concealment and then to the Physical Resource of Area of Operation. Interrogation of the Adversary Plans function will replace the current resource view (within-panel association) with depictions of all means-end linked resources at the Technical Functions & Contextual Effects level (Infrastructure, Communications, Movement & Concealment, see Fig. 2) and simultaneously bring up the first-order decomposition of Plans in the panel immediately below (between-panel associations). In turn, interrogation of the Adversary Communications function will replace the now current resource view with depictions of all means-end linked resources at the Physical Resources & Constraints level (Technical Resources, see Fig. 2) and simultaneously bring up the first-order decomposition of Communications in the panel immediately below. Because Area of Operation and activity within it can be represented geospatially, this means-end chain identifies the value of associating Adversary Resources and Capabilities with the Situation Display.

Activity annotations suggest the manner in which the analyst will need to explore links from Adversary Resources and Capabilities through Technical Functions & Contextual Effects to Physical Resources & Constraints. As an illustration, note from Figs. 6–8 the innovative use of domestic and commercial resources for offensive action (e.g. auto repair shops to assemble explosive devices, garage door openers as remote triggering devices). Such associations offer insight into how insurgents will plan and execute operations.

6. Future work

There is considerable cognitive analysis and design work required as yet to achieve the vision of a fully integrated collaborative workspace. The narrative used for the activity analysis is specifically about one type of current insurgent operation. However, as recommended by Rasmussen et al. (1994), an analysis of prototypical operations is needed to develop a system that has value beyond the specifics of current concerns. It would be shortsighted, even for the current situation, to focus on the specific activity patterns of current insurgent operations because insurgents have shown themselves to be adaptive. Thus, it is important to develop a workspace that examines what is possible as well as what is happening in the current situation. It is this form of generic or prototypical analysis that is needed to enable the analyst to plan for innovative changes or adjustments in insurgency tactics and procedures.

The requirement for the type of resources shown in the pop-up summary for Rules of Engagement (Fig. 12) was identified in the analysis and the depicted summary was taken from a military document (United States Marine Corps, 1998). Nevertheless, the content and form for resources such as this should be developed through an analysis and design process similar to the one used here to develop the workspace prototype but focused on this particular element. Similarly, the types of measures that are important for assessments of System Mission and for Operational Principles & Values require more systematic analysis. Many other elements of the workspace also demand a focused cognitive analysis.

This paper demonstrates a path from analysis to prototype consistent with the design strategy described earlier. Only a fraction of the essential functional properties have yet mapped into the workspace, but even before effort is extended in that direction, it will be useful to develop more concrete ideas for navigation. Probably because the first views are static, little thought has yet been put into navigation, especially navigation back from detailed views to the default view, which will be is essential for smooth operation within this workspace. The development of a dynamic prototype that implements navigational ideas is a high priority for future work.

An underlying assumption of this work, drawn in part from Tufte's (2003) argument that displays should support reasoning about causal relationships by depicting status and trends, is that the analyst is responsible for making inferences and for detecting opportunities but that the workspace supports that cognitive reasoning by clearly revealing functional properties and their relationships. Before converging on a conclusion, the analyst would engage in considerable exploratory activity and may wish to highlight specific features through that process. The actual manner in which this workspace would be used to extract meaningful insights in support of counter-insurgency operations has yet to be examined. This is further reason to pursue development of a dynamic prototype that can be tested in user trials prior to extending the functional capabilities of the workspace.

7. Conclusion

This paper demonstrates a path from analysis to prototype consistent with the design strategy described early in this paper. Nevertheless, the arguments developed in this paper should not be taken to imply that Fig. 10 necessarily illustrates the most appropriate solution to this problem. Although the prototype is the result of formative analysis and design, it remains important to continue the imaginative thinking that could generate more style options for workspace structures. We might question, for example, whether the space allocated to Allied and Adversary resources is adequate for these important functions and if not, how the panel space might be reallocated. A spiral development process, cycling iteratively through analysis, design, prototype

development and user testing, will be required to complete this vision for a functional workspace.

The best general lesson to be taken from this work is that the transition from analysis to prototype demands explicit analysis and design strategies. Those strategies need to specify the information that is to be represented, the structure or organization of the information layout, the representational forms that should be used, and the strategies for accessing, associating and integrating information.

Acknowledgement

This work was completed under Contract F33615-98-D-6000, Asymmetric Adversary Analysis for Intelligent Preparation of the Battlespace, to the Air Force Research Laboratory with Robert G. Eggleston as the technical monitor.

References

Beagle, T.W., 2000. Effects-based targeting: another empty promise? Thesis Presented to the Faculty of the School of Advanced Airpower Studies for Completion of Graduation Requirements. Maxwell Air Force Base, Alabama, Air University School of Advanced Airpower Studies.

Burns, C.M., 2000. Errors in searching for abstraction hierarchy information. In: Proceedings of the XIVth Triennial Congress of the International Ergonomics Association and 44th Human Factors and Ergonomics Society Annual Meeting. vol. 1. Human Factors and Ergonomics Society, Santa Monica, CA, pp. 270–273.

Burns, C.M., Hajdukiewicz, J.R., 2004. Ecological Interface Design. CRC Press, Boca Raton, FL.

Dinadis, N., Vicente, K.J., 1999. Designing functional visualizations for aircraft system status displays. International Journal of Aviation Psychology 9, 241–269.

Eggleston, R.G., Whitaker, R.D., 2002. Work centered support system design: using frames to reduce work complexity. In: Proceedings of the 46th Human Factors and Ergonomics Society Annual Meeting. Human Factors and Ergonomics Society, Santa Monica, CA, pp. 265–269. (CD-ROM)

Gibson, J.J., 1979. The Ecological Approach to Visual Perception. Houghton Mifflin, Boston.

Leung, Y.K., Smith, S., Parker, S., Martin, R., 1997. Learning and retention of auditory warnings. In: Mynatt, E., Ballas, J.A. (Eds.), Proceedings of the Fourth International Conference on Auditory Display. Xerox Palo Alto Research Center, Palo Alto, CA, pp. 129–133.

Linegang, M.P., Lintern, G., 2003. Multifunction displays for optimum manning: towards functional integration and cross-functional awareness. In: Proceedings of the 47th Human Factors and Ergonomics Society Annual Meeting. Human Factors and Ergonomics Society, Santa Monica, CA, pp. 1923–1927 (CD-ROM).

Lintern, G., 2002. Work domain analysis for distributed information spaces. In: Proceedings of the 2002 International Conference on Human–Computer Interaction in Aeronautics (HCI-Aero 2002). American Association for Artificial Intelligence Press, Menlo Park, CA, pp. 94–99.

Lintern, G., 2005. Work Domain Analysis: Tutorial (June, 2005, http://kn.gd-ais.com/Database/DocMan_Upload/Staging/Tutorial_on_WDA.pdf)

Lintern, G., Waite, T., Talleur, D.A., 1999. Functional interface design for the modern aircraft cockpit. The International Journal of Aviation Psychology 9, 225–240.

Lintern, G., Miller, D., Baker K., 2002. Work centered design of a USAF mission planning system. In: Proceedings of the 46th Human Factors and Ergonomics Society Annual Meeting. Santa Monica, CA, Human Factors and Ergonomics Society, pp. 531–535 (CD-ROM).

Pejtersen, A.M., 1992. The BookHouse: an icon based data base system for fiction retrieval in public libraries. In: Cronin, B. (Ed.), The Marketing of Library and Information Services. ASLIB, London, pp. 572–591.

Rasmussen, J., 1998. Ecological Interface Design for Complex Systems: An example: SEAD—UAV Systems (AFRL-HE-WP-TR-1999-0011). Human Effectiveness Directorate, Crew Systems Interface Division, Wright-Patterson Air Force Base, OH.

Rasmussen, J., Petjersen, A.M., Goodstein, L.P., 1994. Cognitive Systems Engineering. Wiley, New York.

Reed, E., Jones, R., 1982. Reasons for Realism: Selected Essays of James Gibson. Lawrence Erlbaum Associates, Hillsdale, NJ.

Tufte, E.R., 1997. Visual Explanations: Images and Quantities, Evidence and Narrative. Graphics Press, Cheshire, CT.

Tufte, E.R., 2003. One-Day Course: Edward Tufte, Presenting Data and Information, New York.

United States Marine Corps, 1998. Military Operations on Urbanized Terrain (MOUT). Marine Corps Warfighting Publication (MCWP) 3-35.3. Department of the Navy, Headquarters United States Marine Corps, Washington, DC (November, 2004, http://www.globalsecurity.org/military/library/policy/usmc/doctrine/mcwp3353.pdf).

Vicente, K.J., 1999. Cognitive Work Analysis: Towards Safe, Productive, and Healthy Computer-based Work. Lawrence Erlbaum & Associates, Mahwah, NJ.

Vicente, K.J., Rasmussen, J., 1992. Ecological interface design: theoretical foundations. IEEE Transactions on Systems, Man, and Cybernetics 22, 589–606.