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The Future of C2

Title: Cognitive Work Aids for C2 Planning: Actionable Information to Support Operational Decision Making

Topic: Decisionmaking and Cognitive Science

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Abstract

As the Department of Defense (DoD) moves toward a net-centric environment, all the services are becoming increasingly dependent on information technologies (IT) to process data, present relevant information, and aid Command and Control (C2) "work". Just as the amount of available data and reliance on IT increase, so do the challenges of providing, in as concise a form as possible, only the relevant and "actionable" information needed to support C2 operators. This paper describes a design for a global mission planning C2 work aid. The discussion describes a cognitive based design approach to developing work aids called Work Centered Support Systems (WCSS) and demonstrates the actionable information used in an operational scenario to optimally support critical decision making. Although the work aid is demonstrated in a global mission planning scenario, the WCSS visualization principles can be applied to a variety of air operations C2 work.

Introduction

Advances in information technology have transformed the use of information in the military. C2 operators currently have access to enormous amounts of battlespace data in near-real-time. This data often arrives in piecemeal fashion from a variety of sources, burdening operators with the overhead effort for finding, interpreting, fusing and acting on the relevant information in order to successfully accomplish their work. For example, they often must navigate through multiple applications, menus, dialogue boxes and other "data-centric" layers of "displays" just to collect the information critical to specific decision-making tasks. This causes many problems such as increased cognitive demand, reduced situation awareness, diminished productivity, and ultimately a degraded war fighting capability. Since the data systems are typically not designed to support the cognitive aspects of work, gathering the data is only the start of the overhead imposed by the system. Once gathered, the operator must "mentally fuse" or transform the data in off-line calculations to arrive at the needed value or format to support effective decision making. In order to take full advantage of the capabilities of a net-centric environment, the C2 operator of the future must have relevant, actionable information at their fingertips. In order for "decision support systems" supporting future C2 operations to be optimally effective, greater emphasis must be placed on cognitive and work-centered issues during systems design and development.

This paper describes applied research being sponsored by the Air Force Research Laboratory (AFRL) on Air Mobility Command C2. The paper will first describe our cognitive based approach to developing work aids called Work Centered Support Systems (WCSS). WCSS facilitate C2 decision making performance by exploiting advanced visualization and automation to keep users on topic, focused, and well-informed. More specifically, WCSS enhance visibility of mission-critical decision factors, depict relationships between mission plan elements and constraints, and highlight problematical conditions. We shall then review the work-centered design (WCD) methodology we've developed and illustrate its application in the context of our most

recent C2 innovation effort. We shall conclude with a scenario demonstrating the utility and advantages of this effort's design concept.

Air Mobility Command Tanker Airlift Control Center (TACC)

AMC is headquartered at Scott AFB, IL, along with its air and space operations center (AOC) for centralized command and control, the Tanker Airlift Control Center (TACC). The TACC schedules and tracks strategic tanker and airlift resources worldwide. Air Force and Department of Defense support taskings are channeled through this state-of-the-art mobility C2 hub. It is a global AOC with several hundred people planning and executing around 350 missions per day.

Mission planning is an activity undertaken by AMC in response to United States Transportation Command (USTRANSCOM) requests to move military equipment and personnel by air. Mission planning is a complicated activity that must take into account issues such as matching loads to currently available aircraft, landings in and over-flights of foreign nations, competing airlift demands, airfield and airspace constraints, air refueling requirements, aircrew constraints, and equipment constraints.

There is a basically linear process path leading from mission planning through detailed planning of mission factors (e.g., routes, permissions) to mission execution. The focus of this work is an operational domain that is both complex and dynamic. Changes may occur at any time, and the range of actionable events or conditions is essentially unconstrained. Relevant decision making factors are numerous, situation-specific, and interrelated in complicated ways. Though planning may have begun months in advance, it is not until a few hours prior to launch that a plan can be finally evaluated for adequacy and feasibility. Once the mission is in progress, C2 becomes an extremely time-sensitive and time-critical function.

These operations are conducted by a staff of specialists. Mission Planners conduct initial mission planning in response to incoming USTRANSCOM requirements. As time goes on, other specialized roles contribute detailed specifications to this plan. For example, Barrelmasters allocate resources and task missions, units assign aircrew and aircraft, Aerial Port Control Center staff work out load (passenger and cargo) logistics, diplomatic clearance (DIP) specialists obtain overflight permissions, and Flight Planners lay out details of routing and timing of crossing points. As launch time approaches Flight Managers (FM) finalize payload information, routing, flight plans and required permissions, and assemble aircrew documentation, to include diplomatic clearances, computer flight plan, Air Traffic Control (ATC) flight plan, air refueling, Notices to Airmen (NOTAM), and weather forecasts generated by meteorological specialists.

Twenty-four hours prior to planned mission launch, responsibility for the mission is transferred from the Mission Planner to the Execution Cell that is responsible for handling any last minute changes and dealing with any problems that might arise during mission execution. The Execution Cell is manned by a Senior Officer, Duty Officers (DO), enlisted controllers, and FMs that are responsible for identifying, tracking, and resolving problems. Typically the enlisted controllers or FMs receive calls from pilots

or the wings alerting them to problems (e.g., diplomatic clearances, prior permission required (PPR), aircraft maintenance problems; delays in loading cargo; unanticipated changes in payload; airfield closures). Difficult cases are escalated to the Senior or a DO who is responsible for identifying potential repercussions for the current mission as well as follow-on missions and modifying mission plans to resolve any problems identified.

Legacy, data centric computer systems support management and execution of TACC airlift and air refueling missions. They are intended to provide accurate, near-real-time data required for making decisions on effective use of AMC resources. This data is presented to TACC users via Microsoft Windows compliant user interfaces. However, simple presentation of all available data does not ensure effective support for TACC users' work activities. Critical information is not always available at the right time or in the right format to support decision making and other cognitive work activities.

Work Centered Support Systems

Work-centered support systems (WCSS) have been a focus of AFRL research and development projects since 1999. The WCSS concept and the *work-centered design (WCD)* methodology through which they are generated have evolved within AFRL projects addressing C2 operations within TACC.

A WCSS is a client that "plugs" into net-centric data services, links to the right information, and "knows" how to effectively present it (Young *et al.*, 2000). A WCSS affords its user(s) an optimal 'window' onto their work subject matter, in the sense that it is tailored to provide effective information support for the task(s) at hand plus the functions necessary to accomplish the users' work activities. WCSS visualizations depict the problem space from a user's perspective, including constraints and possibilities, so as to aid user memory and "suggest" solutions (Eggleston & Whitaker, 2002). Automation is fit into the natural flow of work activity by using intelligent agents to find, fuse and embed relevant information in these visualizations. In a good WCSS design, the user can address essential elements of work on the same terms as he / she cognitively engages them. By facilitating attention to the work and not the system or tool itself, a WCSS affords the user improved situation awareness on his/her overall workstream, the facts of particular 'cases' within that workstream, and the state of the task(s) at hand in processing each 'case'. In other words, WCSS supply the right data for the task at hand, minimize overhead associated with finding and fusing this data, and effectively convert this data into actionable information.

Work-Centered Design Methodology

WCD's goal is to generate effective WCSS designs by crafting data visualization, navigation, and manipulation to reflect and accommodate actual work practices. This is the optimum approach for effectively supporting the key components of information-intensive C2 tasks - decision-making, collaboration, work management and work product generation (Eggleston, & Whitaker, 2002). Our WCD methodology builds on work in cognitive engineering (e.g., Rasmussen, 1986; Woods and Roth, 1988) and cognitive work analysis (e.g., Vicente, 1999) to overcome prior limitations in applying cognitive research to practical settings (Eggleston, 2002, 2003). We conduct WCD as a team

incorporating 3 expert roles - cognitive engineer, WCSS designer, and software engineer. All 3 roles actively participate throughout the WCD process.

The WCD process can be seen as involving two major phases - *problem analysis* and *design synthesis*. The problem analysis phase is dedicated to understanding the target use situation and identifying 'problems' in need of constructive intervention. Conventional engineering models such as IDEF (Integrated Computer-Aided Manufacturing (ICAM) DEFinition) do not lend themselves well to analysis of computer supported tasks, especially ones involving high cognitive demands and situation-specific decision criteria (Kremer, 2005). Such engineering approaches tend to focus on models whose quality is judged more with respect to formal coherence than fidelity with respect to the actual work 'ecology' (environment; context). As a result, such models often oversimplify work practices, overlook context dependencies in the work domain, and overemphasize abstractions relative to workers' perception of and experience with the target work. In WCD, we do not presume the work has to conform to a given model. Instead we seek to generate a model which conforms to the empirical evidence. The problem analysis phase begins with knowledge acquisition (KA) and progresses through analyses of work processes and work 'ecology' (operational context).

In knowledge acquisition, the WCD team reviews existing documentation; performs field observations; and conducts structured interviews in order to understand the cognitive requirements of work and the kinds of complications that arise in the domain that create problem-solving and decision-making challenges (Potter, *et al.,* 2000). The WCD methodology emphasizes analysis of work as practiced. The focus is on examining situated decision-making, identifying hard cases, recurrent error conditions, work-arounds, and informal artifacts that domain practitioners have developed to compensate for limitations of legacy systems as evidence of currently unsupported aspects of the work (Roth and Patterson, 2005).

As this phase progresses, the WCD team generates a body of knowledge on the work to be supported, the environment that shapes and constrains work activities, and significant issues and problems affecting work performance and quality. We develop models of the work 'topology' (i.e., the 'configuration' of its process flows, its constraint space, etc.). We generate use cases, scenarios, and storyboards to illustrate current and prospective operations. These products are recursively developed and refined in ongoing interactions with domain practitioners. This sets the stage for the design synthesis phase.

The design synthesis phase exploits the results of the first phase to create constructive interventions in the form of WCSS. This phase begins with conceptual design and progresses through WCSS development and evaluation. In this phase, an optimal perspective ('vantage') on the task's focal subject matter is identified as the basis for work-centered visualization, and this visualization concept is refined and augmented with functional features to comprise a WCSS prototype specification. A functional prototype is then developed, presented to domain practitioners in the context of realistic use cases, and recursively refined in accordance with their feedback.

We have been studying AMC TACC operations as part of WCSS prototype development projects since 1999. Initial KA focused on the activities of Channel Planners (who have the responsibility of planning regularly scheduled missions moving cargo and people) and resulted in the development of modular applications to support mission status alerting and evaluation of Maximum-On-Ground (MOG) conditions at airfields (Mulvehill and Whitaker, 2002). The functionality demonstrated by the former has proliferated within subsequent TACC support tools, and the visualization concept of the latter has been deployed in multiple applications since 2000. In subsequent projects we then examined the work activities of FM and weather forecasters. This led to the development of several WCSS designs. Two of these - a modular notepad for FM planning tasks and a WCSS to help weather forecasters identify weather conditions that can impact mission execution (Scott, et al, 2005) - are currently in daily use in the TACC.

Our most recent project, WIDE, is focusing on the larger mission planning process, encompassing both the initial planning performed by mission planners and the replanning activities that occur during execution in response to unanticipated events.
In the following sections we shall illustrate the WCSS concept and our WCD methodology with an example drawn from this current effort. This example involves a 'timeline display' WCSS concept developed to aid C2 staff in the planning and execution of air mobility missions. Our illustrative discussion will proceed in the same fashion as our WCD methodology - moving from analysis of the target operations to development and demonstration of a WCSS conceptual prototype.

The Problem Analysis Phase

KA activities were conducted during three multi-day site visits to the TACC that occurred March, July and December 2004. KA activities included interviews with Planners and Execution Cell personnel to allow us to understand the 'as is' mission planning and execution process, the factors that complicate planning and execution, and the kinds of miscommunications and errors that can produce mission delays and cancellations. Observations of actual operations in the TACC were also conducted. Analysts sat with the Senior, DO, and controllers and observed them as they handled actual cases. This provided an opportunity to identify and document cases illustrative of the kinds of complexities that can arise and how they are handled, as well as to observe the kinds of work-arounds and informal artifacts that the Senior, DOs, and controllers have developed to cope with limitations in their existing software support systems.

Among the main findings of the analysis is that a mission plan involves consideration of multiple factors that interact with and constrain each other. These factors include type of aircraft, type of payload, countries to be flown over, and airfields where intermediate stops will occur. Any change in one factor can have repercussions for other factors. For example an unexpected change in payload (e.g., the presence of unplanned hazardous material) can influence the viability of the planned route because some countries do not allow flights with such payload. Similarly, a delay in the flight (e.g., due to an aircraft maintenance requirement) can have further repercussions for a mission. For example, it may cause a flight to reach an airfield after it has closed or result in a violation of air crew duty day limitations.

The initial mission plan generated by the Mission Planner takes these multiple factors into account. However, unanticipated changes can arise between the time the mission is initially planned and when it is executed. The Senior and DO have to be able to understand the goals and constraints in the mission plan initially developed by the Mission Planner and assess the implications of these last minute changes for the viability of the flight. The current information systems available in the Execution Cell do not effectively support the Senior or DO in assessing the impact of changes on the viability of a flight plan and revising the plan appropriately. Although all the relevant data is available, it is presented in a tabular, data centric form that makes it difficult to get a 'holistic' understanding of the elements of the mission plan and the objectives and constraints that underlie it.

Let us illustrate this situation with regard to the concrete example of a mission delay. Currently, TACC staff must notice that a mission has not departed on time and then react. Current systems do not offer proactive alerting on such conditions, leaving it to the user to recognize a departure variance's occurrence by details of the state of one or another passive data display. For example, the user may note an apparent delay based on the relative position of a mission entry (being "above the line") on the Global Decision Support System (GDSS) Mission Monitoring and Management Client (M3C) Display (Figure 1).

MISSION DISPLAY, Filter: ACTIVE MISSIONS, NCOIC, ALL, A As Of 0242/1907Z

ACTIVE MISSIONS # * Missions: 310-334 Total: 334

Msn #	Owner	Tail	MDS	ICAO	Status	Time	F	ICAO1	ICAO2	ICAO3	DIPS	CW	PRI	CM	MsnDev
TKPW27900203	AAL	N1758B	MD011	RJTY	INB	0203/2330		KSEA	KLAX				3A3		0.0
QENRKA330203	910AW	19142	C130H	KBOI	DEP	0204/1500		KYNG	KBGR	KYNG			5A1		0.0
ABB02V3PC203	97AMW	00451	C005A	LERT	INB	0204/2000		LICZ	LERT	KNGU	App		1B3	Y	-14.0
1JB0900KC187	16SOW	60225	MC130P	KIKR	DEP	0204/2111		KVPS					4B3		-5.2
VVBGKM400206	62AW	50251	C141B	KADW	DEP	0206/2245		KJAN					1B3		-4.0
BKBZE38TE207	AMT	N188AT	L10115	KBWI	DEP	0208/0200		ETAR	KBWI				3B1		-5.5
1CM0600UA300	16SOW	96642	UH001N	KNGP	DEP	0210/1400		KHRT					5A1		-720.0
M3TESTDO1234	161ARW	80116	KC135E	LTAG	DEP	0216/0224		KPHX			Req	Y	2A1		0.9
M3TESTDO1238	161ARW	80116	KC135E	LTAG	DEP	0216/0224		KPHX			Req	Y	2A1		0.9
M3TESTDO1239	161ARW	80116	KC135E	LTAG	DEP	0216/0224		KPHX			Req	Y	2A1		0.9
BQAZZ11TE215	AMT	N195AT	L10111	KBWI	INB	0217/0415		KWRI					3B1		-24.0
M3TESTCONTR2	161ARW	80116	KC135E	LTAG	DEP	0221/0000		KPHX			Req	Y	2A1		0.9
BKNLA02TE222	AMT	N190AT	L10115	ETAR	INB	0222/1800		KWRI					3B1		-3.5
BKBXE22CM226	UPS	N707UP	DC008	KBWI	DEP	0227/0630		KWRI					3B1		-2.4
BKBXE22CM228	UPS	N819UP	DC008	OKBK	DEP	0228/0700		KBWI	KWRI				3B1		
BQABR20TE227	AMT	N194AT	L1011A	OEKJ	DEP	0228/1130		ETAR	KWRI				3B3		
PBB30X500175	62AW	67067	C141B	KWRI	DEP	0231/0500		LPLA	ETAR	KWRI			1B3		0.0
ABA07F300200	305AMW	60168	C141B	KNGU	DEP	0231/1915		CYQX	LICZ	OBBI	Req		3A3	Y	-746.5
XQCRJ4400232	445AW	50232	C141C	PHIK	INB	0232/0810		KSUU	KRIV				1B3	Y	0.0
QENRTA014189	152AW	37777	C130E	KMKE	INB	0234/1905							5A1		999.9
DAYTON002238	374AW	37790	C130E	RJTY	INB	0238/2210							5A1		-0.2
ABBBROKST241	436AW	60023	C005B	KCHS	DEP	0241/1745		KDOV	KCHS	KDOV			3B3	Y	-0.3
Current	**Time**	**Line**				**0242/1907**									
UQU09W80A230	86AW	96582	C130E	ETAR	INB	0249/1930							1B1		-456.0
1UB0400GA171	16SOW		AC130U	KWRB	DEP	0263/1400		KVPS					4B3		0.0

Response Completed

Figure 1: GDSS M3C Mission Display

Even those systems offering dynamic alerts rely on the users' vigilance. TACC's widely-used Integrated Management Tool (IMT) display spans 3 large monitor screens with a single tabular listing of all mission records containing approximately 80-90 columns of mission data (Figure 2). The size and visual complexity of this display makes it difficult to notice alerts as they occur.

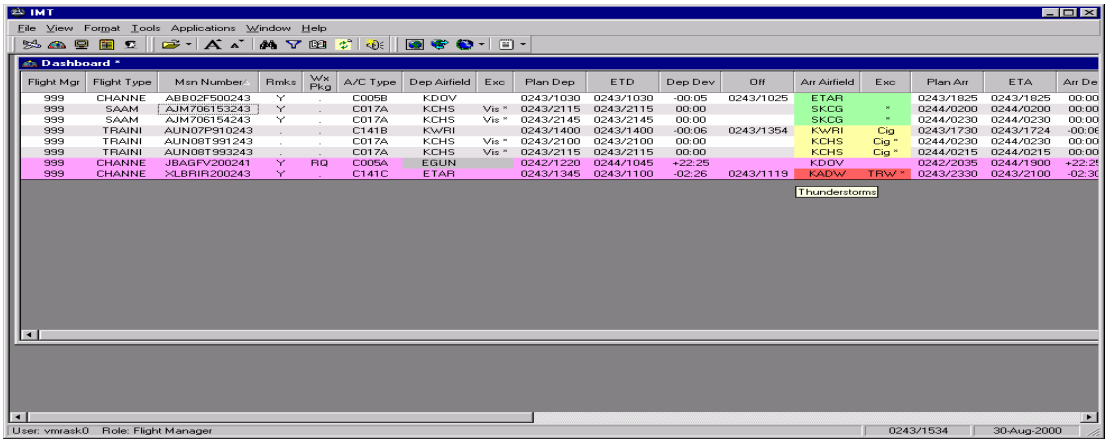


Figure 2: IMT Display

These shortcomings and attendant burdens extend beyond problem recognition. To research the background and causes for such a problem, TACC staff must usually search through advisories and remarks in the GDSS Mission Detail (Figure 3). For very recent or realtime problem conditions, the system provides no indication of the reason for the delay, or how long it is likely to last and the staffer must resort to a phone call to inquire about the mission. Once the Senior, DO, or controller has the facts, he / she must search for repercussions of the problem by navigating through several separate sections within the Mission Detail and then mentally calculating whether derivative impacts will result. Re-planning activities get bogged down in trying to determine whether or not candidate solutions will result in more problems. There is no visualization or computational support for these cognitive activities with current systems.

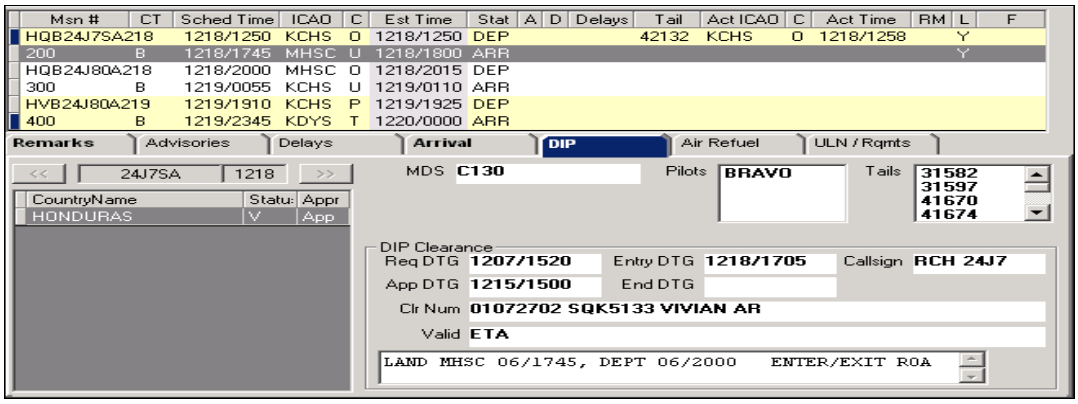


Figure 3: Mission Detail Diplomatic Clearance (DIP) TAB

As a consequence it can take the Senior or DO tens of minutes to fully grasp the implications of a last minute change on the viability of a mission and to determine what modifications to the mission are required. In addition, there have been cases where the Execution Cell failed to recognize repercussions of a last minute change (e.g., violations of airfield operating hours; crew duty hours; or diplomatic clearance permissions), resulting in aircraft being diverted, or missions having to be severely delayed or aborted.

The analysis identified a number of ‘leverage points’, or opportunities for more effective work-centered support. These included:

- More effectively communicating the mission plan and constraints that underlie it;
- Alerting to emerging problems (e.g. delays) that threaten the viability of a mission;
- Facilitating the ability to assess repercussions of mission changes (e.g., delays) on the current and subsequent missions (e.g., reaching an airfield after hours; violating crew rest requirements; violating diplomatic clearance time limits).

The analysis revealed a need to make information about mission events and relevant constraints more readily and more meaningfully apparent. This would enable Senior, DOs, and controllers to assess repercussions of plan changes more quickly by reducing demands for looking up information and performing mental calculations. Similarly, it would reduce the possibility of error by reducing the need to rely on memory and mental calculations, as well as by flagging impacts of mission changes on subsequent portions of a mission or subsequent missions farther out in the planning horizon that might otherwise be missed.

The Design Synthesis Phase

The atomic unit of work reference in this C2 environment is a 'mission'. All work activities in the command center are ultimately framed with respect to one or another mission. This mission-centric orientation was consistently evident when examining TACC both 'horizontally' (along the process path from planning through execution) and 'vertically' (upward and downward through layers of supervision and command). Command center staff are consistently required to identify and evaluate the state of a given mission by 'connecting the dots' among diverse data sets drawn from multiple legacy systems.

Obtaining a coherent perspective on a given mission therefore involves significant procedural and cognitive burdens for locating, combining, and analyzing the relevant data. The daunting complexities and dynamics of the subject matter only add to these burdens, and on top of all this there is the pressure of time-criticality during mission execution. Taken together, these factors weigh on individual and team performance and heighten the risk of errors.

A constructive WCSS intervention would need to provide unified and coherent situation awareness capable of focus at the granularity of an individual mission. It would need to accommodate the range of factors (states, constraints, opportunities, etc.) affecting mission viability. To achieve this, the prospective WCSS application would need to afford users a representation of mission-critical data framed with respect to a single referential framework. This referential framework needed to be one capable of portraying the widest range of relevant data in a useful way. In our analysis of mission planning and execution, we had discerned that for most purposes the C2 personnel were addressing a mission in terms of it being an event - a complex procedure being enacted as

an interplay of assets within a prescribed timeframe. As a result, we identified 'time' as the primary dimension for framing and correlating mission data.

The next step involved 3 main thrusts. The first was to inventory the subject matter (data) that needed to be made available as the WCSS interface's 'content'. The second was to organize this content with respect to empirically-evident ontological and epistemological criteria. The third was to characterize this material in such a way as to be consistently and coherently mapped onto a temporal coordinate schema.

We first laid out a schema to serve as our conceptual framework for addressing and organizing the relevant material. This schema consisted of 3 elements. An *event* was a particular action, state, or change of state occurring (or expected to occur) at a specific point in time. Such events could be portrayed with respect to the *resources* (assets, entities, objects) involved in their occurrence. We could ascribe *conditions* (states, characteristics) to both events and resources. The interrelationships between conditions pertaining among the set of events and resources would provide the basis for representing key decision factors such as constraints and opportunities.

Because one event may involve multiple different types of resources, we determined that distinctions among resources were the most useful bases for categorizing the relevant subject matter. In the end, we arrived at a set of resource-related categories as follows:

- *Geographic Elements* - Geo-spatial factors correlating with the mission such as nations overflown, departure and arrival airfields, control areas, etc.
- *Aircrew Elements* - Elements relating to the crew such as availability times, crew rest periods, and return dates.
- *Aircraft Elements* - Elements such as availability time, required maintenance periods, etc.
- *Airfield ('Port') Elements* - Elements such as operating hours, closures, etc.
- *Ground Events* - Elements such as loading / unloading times, refueling times, etc.
- *Load / Cargo* - Elements such as arrival / availability schedules, etc.
- *Permissions* - Elements such as diplomatic clearance periods, prior permission required (PPR), etc.
- *Aerial Refueling (AR)* - Elements such as scheduled tanker rendezvous, tanker and receiver status, etc.

These eight resource categories (termed *clusters*) were to serve as the modular sub-frameworks for comprehensively representing mission factors relative to time. To provide a summary point of reference for users, we then devised a 'Core' set of data which would serve as both (a) the 'short-form' summary timeline representation of a given mission and (b) the focal component within a presentation of multiple clusters.

Based on our analyses, we chose a limited set of features to be portrayed in the summary 'Core'. These included a general timeline of events, aerial refueling (AR) timeframes, projected time in air, geo-spatial areas being overflown, and diplomatic clearances

(DIP's) associated with these overflown areas. The inclusion of AR and DIP data was based on the priority assigned to these topics by users as foci of attention and sources of problems. In other words, our prioritization of these elements corresponded to their importance from the user's first-person perspective.

The modularity of 'summary / core' versus 'detailed cluster' representations afforded us the ability to meet two distinct needs among the target users. A set of 'core' summaries could be presented to give situation awareness over multiple missions (something needed by supervisory staff and execution phase monitors). A complete set of clusters for a given mission would be most useful for personnel focused on (re-)planning or analyzing one particular mission. This conceptual model provided the basis for a concrete Timeline Tool prototype as discussed in more detail in the following section(s).

Our work-centered orientation gave us the basis for understanding and analyzing the actual domain in which work subject matter and work activities interact. By focusing on the work and the actual workers, we were able to maintain a focus on real problems affecting actual operations. By the time we had concluded our problem analysis and conceptual design work, we had generated a coherent intervention strategy interrelating technical innovations with operational and functional payoffs, as outlined in Table 1.

Table 1: Summary of Intended Timeline Tool Payoffs

FUNCTIONAL ENHANCEMENTS *Payoffs relating to individual performance*	Better inform TACC staffers via: • Fused visualization of disparate mission elements' interrelationships • Ability to perform 'what if' simulations to support decision making. Enable TACC staffers to: • More effectively plan and monitor missions • More effectively recognize and respond to mission problems
OPERATIONAL ENHANCEMENTS *Payoffs relating to team and organizational performance*	• Provide better situation awareness (SA) on mission events and hence on mission viability • Make interactions and constraints associated with events visible • Provide mission 'timeline' visualization
TECHNICAL INNOVATIONS *The means employed or created to achieve the payoffs*	• Fusion of all relevant data and correlation with a 'time context' • Ability to address and manipulate temporal data relating to different events and phenomena • Coherent linear 'timeline' schema into which relevant data on (e.g.) events can be mapped • Access to the varied data / database resources within TACC (e.g. Schedule, Route and Resource data) • Automated support (agents) to evaluate mission parameters and cue users on any problematical states, constraints, etc.

A WCSS Concept for the TACC

The Timeline Tool is designed to be a coherent component of a broader WCSS concept to support TACC operations. This concept results from a culmination of cognitive analysis and WCSS design work in the TACC dating back to 1999 (Mulvehill & Whitaker, 2002). We have identified several visualizations of mission data which, as a set, allow one to efficiently handle most if not all planning and execution tasks including resolving emergent problems.

A WCSS Suite for Mission Planning and Execution

We start our description of the design for the timeline tool in the context of a future mission planning work aid suite as depicted in Figure 4. A user's top level 'window' into TACC operations is the Workstream Overview Summary. This provides an indexed set of all pending missions (Scott, et al. 2005). From this starting point the user is able to 'drill down' to subsets of this pending workstream and / or individual 'cases' (missions).

The Timeline Tool consolidates relevant mission data into a fused mission / sortie 'temporal' (timeline of events) display. A geospatial display called the Flight Visualization Tool (FVT), consolidates relevant mission data into a fused geo-spatial ('map') display. Both the timeline and geo-spatial views are 'team-wide' in the sense that they are useful to all roles involved in the process path from initial planning through to execution. Each of these detailed views allows the user to invoke the other. The intended navigation opportunity among these 3 elements is depicted in Figure 4.

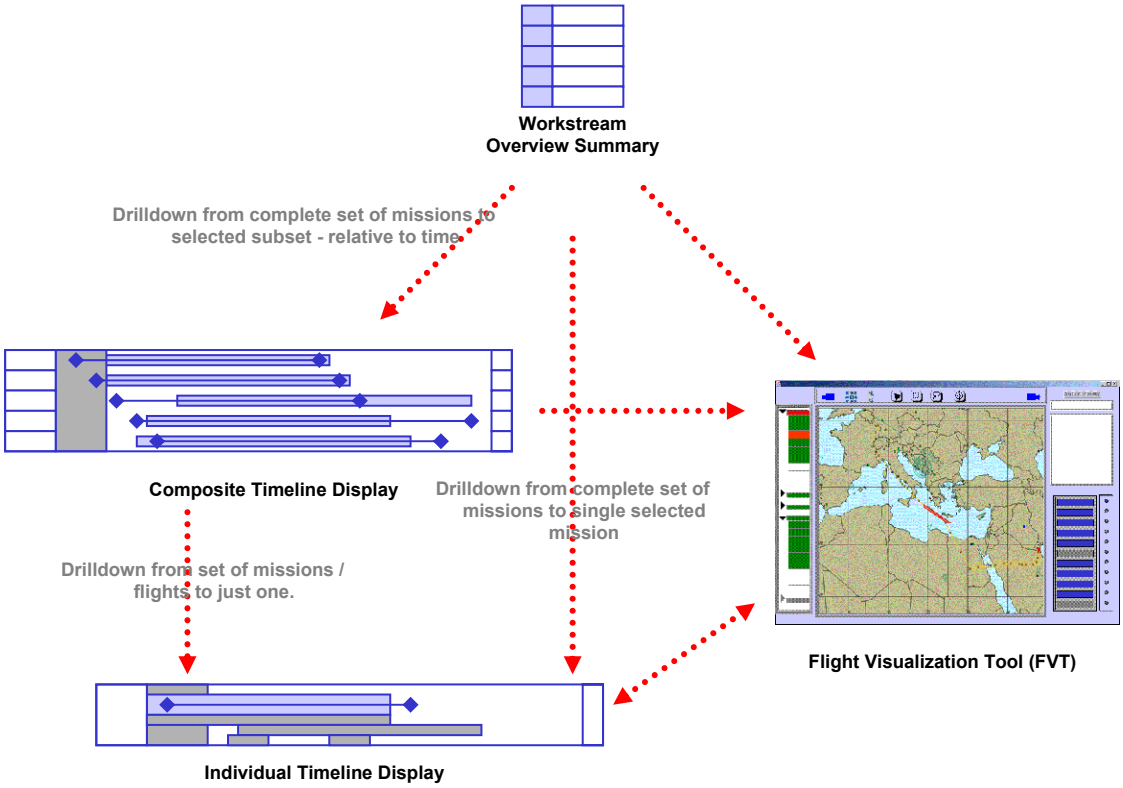


Figure 4: Mission Planning Work Aid Navigation Concept

The Timeline Tool

The Timeline Tool is composed of two similarly-structured interface units - a Multi-Mission Display and Single Mission Displays. A Single Mission Display also includes a simulation mode to provide a capability for performing "what-ifs" to determine the impact of modifying mission factors. This section will describe the main features of the Timeline Tool.

Multi- Mission Timeline Display

The multi-mission display provides a basic overview capability across a set of missions as shown in Figure 5. Such a Multi-Mission Display affords a user summary situation awareness (SA) across a set of mission records selected and organized to suit immediate needs. For example, a DO may wish to invoke a summary of all the missions departing from a particular port or all missions of a particular type, etc.

Each entry gives basic 'timeline' info for individual missions / flights and includes cueing for alerts, ports, temporal context, and planned versus actual / projected flight progress. This display also offers the capability to drill down on a mission /flight for a more detailed view. These features realize the intermediate level of referentiality depicted in the navigation concept (Figure 4). The visual consistency we enforce between 'Core' usage in single- and Multi-Mission Displays facilitates user situation awareness and reduces cognitive burden.

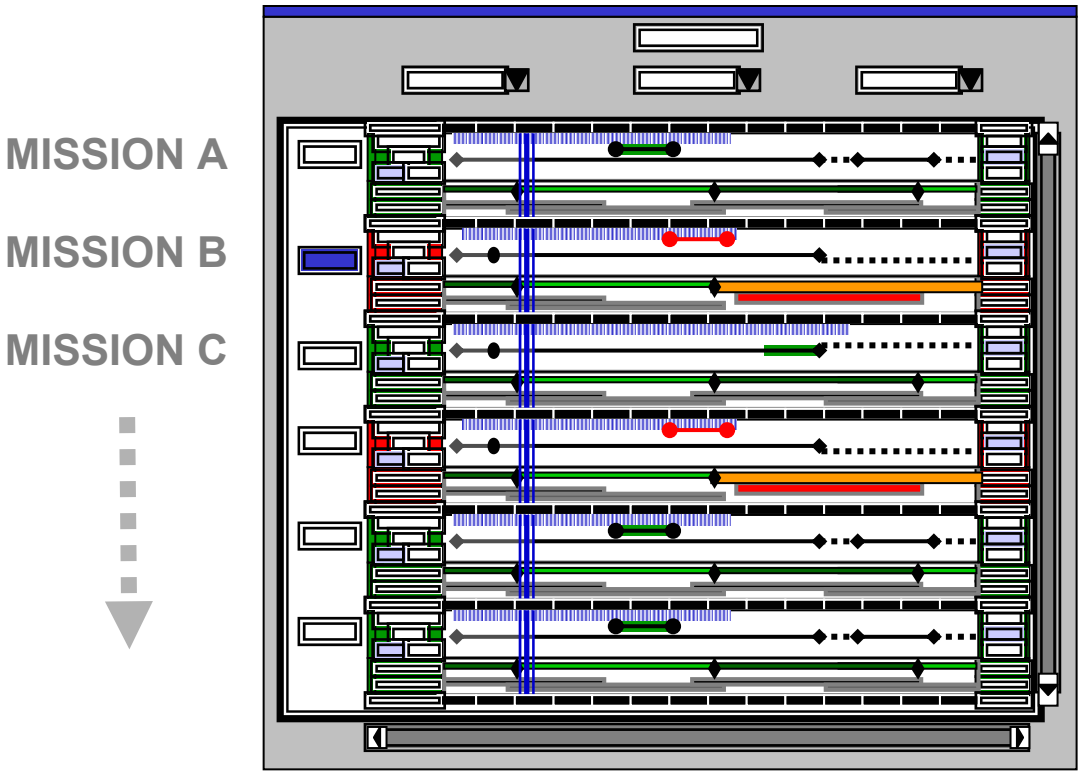


Figure 5: Multi-Mission Timeline Display

Single Mission Timeline Display

The Single Mission Display provides a basic visual syntax for portraying missions (flights and/or sorties) as they correlate with time. The Single Mission Display is comprised of a summary Core element and related 'clusters' of relevant mission data, all on the same timescale, as depicted in Figure 6. Peripheral controls (e.g. drop down lists) permit users to determine what they are viewing, how it's arranged, and at what level of (temporal) granularity it's presented.

The Core element provides a concise summary 'picture' of the most critical flight-related information. The Core serves as an overview for a given mission and the primary / starting visualization component for the Single Mission Display. Overall mission alert status will always be visually indicated on the Core. This coding cues the user on any need to analyze the nature and source of a problem via the more detailed cluster visualizations. The supplemental clusters afford insight into the problem and "suggest" solutions to fix the problem within a common time reference. A scenario discussed in the next section will highlight a few of this aid's alerting and visualization capabilities.

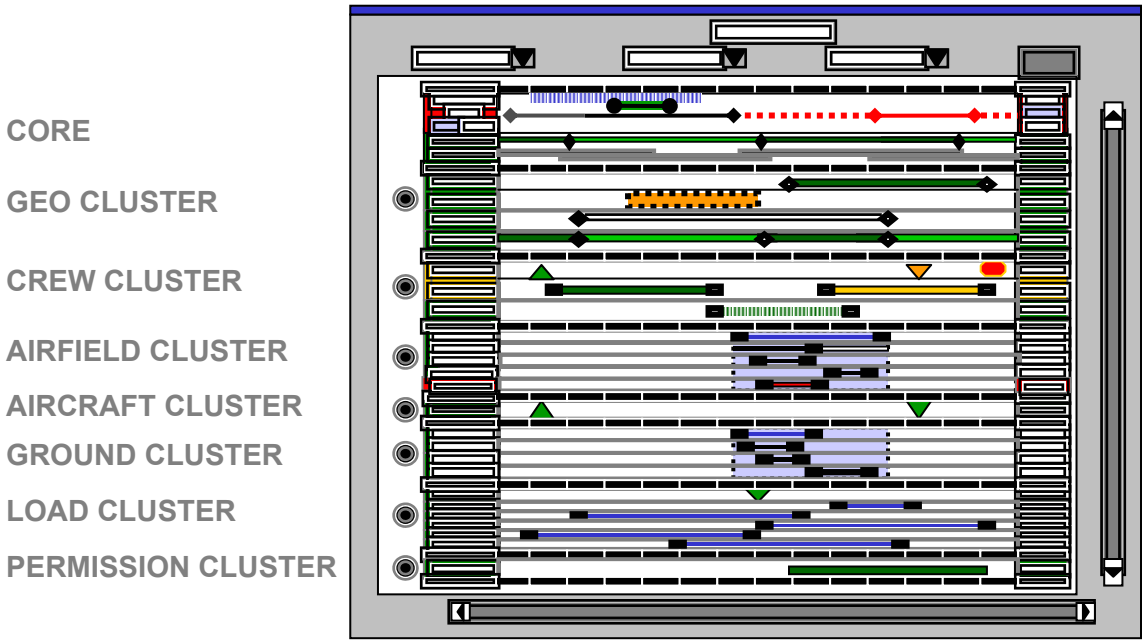


Figure 6: 'Individual Timeline Display' Basic Layout

Single Mission Display Clusters

Clusters are topically-organized sets of time-correlated data related to global air mobility mission planning and execution. As representational units, they provide modular 'sub-windows' on different aspects of the mission's that can be expanded or collapsed to accommodate the current problem focus. The clusters provide visual alerts when critical mission factors are violated and cues to how they can be remedied to ensure a successful mission. Of the eight topical clusters identified in our analysis, the Timeline Tool display makes provision for seven: geographical features, aircrew, airfield, aircraft, ground

events, load (cargo), and permissions. Air events, such as aerial refueling, were deemed critical enough to include in the Core so it is not included as a separate cluster.

Single Mission Display Details

A detailed example of a single Mission Display's Core is shown in Figure 7. The upper portion has a user scalable time index across the top to allow correlation of data elements with Greenwich Mean Time (GMT). Text labels designate which leg is portrayed (1 of N, 2 of N, etc.). The solid lines denote periods in flight and the dashed lines denote periods on ground. An air refueling (AR) availability indicator cues the operator on the scheduled AR reservation period or 'window of opportunity'. The time-in-air' indicator represents an estimate of how long the aircraft can remain in the air during a current (realtime) flight. This cues the user on prospects for continued flight absent any changes. The 'time-in-air' projection will be updated if and when AR is accomplished.

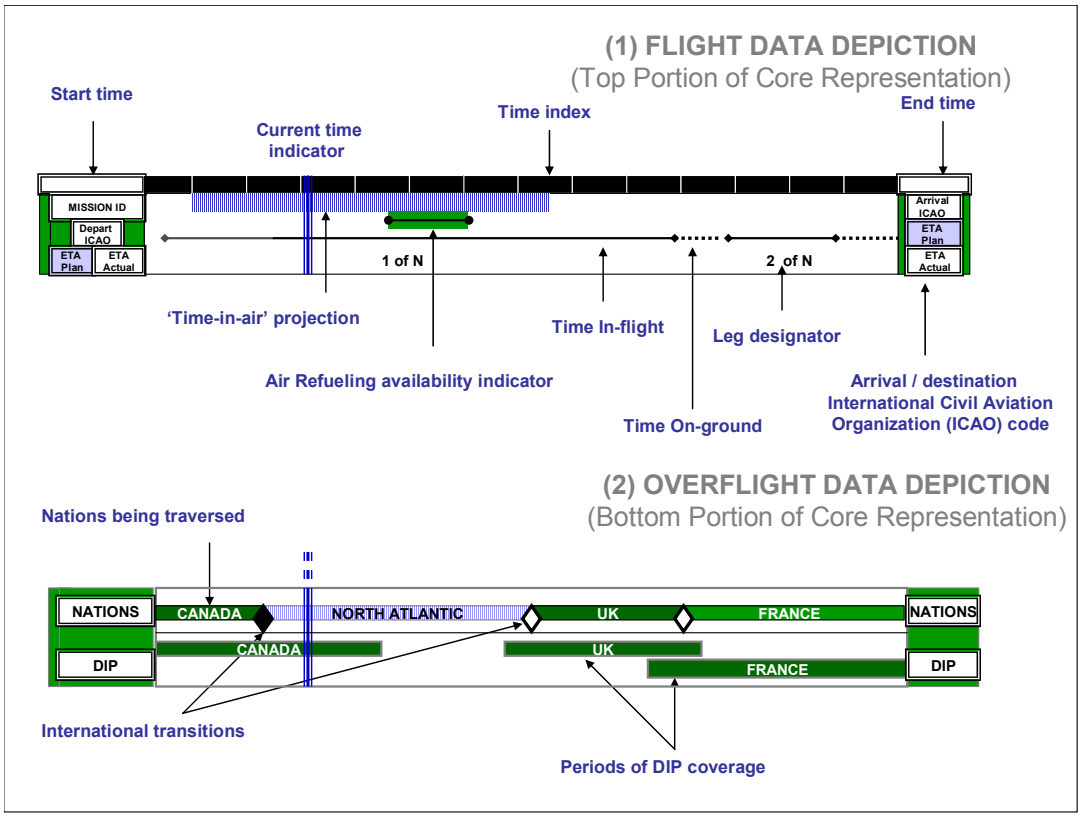


Figure 7: Core Individual Timeline Display Details

The Core's lower portion portrays national overflights and Diplomatic Clearance (DIP) timeslots. The DIPs are approvals for USAF aircraft to fly over a nation. As each mission is planned, the DIPS manager must coordinate and seek diplomatic clearance for each nation overflown. DIPs are typically approved in advance, during the detailed flight planning phase between mission planning and execution. Each country has specific requirements (lead time for approval, and numbers of DIPs allowed, etc.). As the predicted mission times are updated or change during execution, the actual time a mission is over a particular country must remain within the approved DIPs window. Without a

valid DIP, the mission will have to be re-routed, re-planned or cancelled. This visualization portrays the approved DIP 'windows' and hence the thresholds beyond which revisions are required

The key elements displayed in the Core (Flight times, AR time slots, DIPs, etc.) are automatically monitored for correctness. If an event results in one of these factors becoming unfeasible or problematical, an alert is triggered to highlight the affected part of the mission itinerary in both the Core and any related cluster presentations. Such automated alerting at both the overview and detailed levels cue the operator not only on the presence of a problem, but also on where to focus his / her attention in seeking a potential solution.

The Individual Clusters: An Example

We shall now illustrate the layout of a representative cluster that will be emphasized later in our scenario. The Port or Airfield cluster is detailed in Figure 8. This cluster provides a visualization of the factors affecting an airfield's ability to support the given mission. Ops Hours are the hours the port is open for operations. Day/night indicates periods of daylight and darkness. Quiet hours are periods during which take-off and landing may be restricted or prohibited. Bash hours are periods when bird strike hazards are more likely. MOG periods are times during which the number of aircraft at the airfield meet or exceed the official limit.

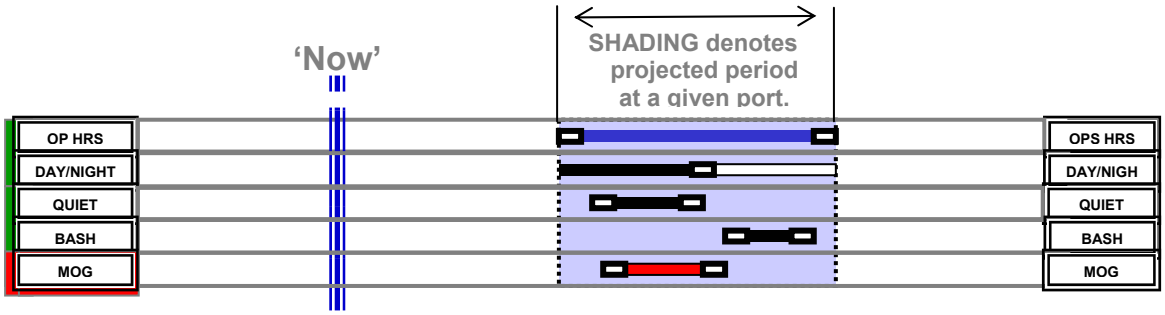
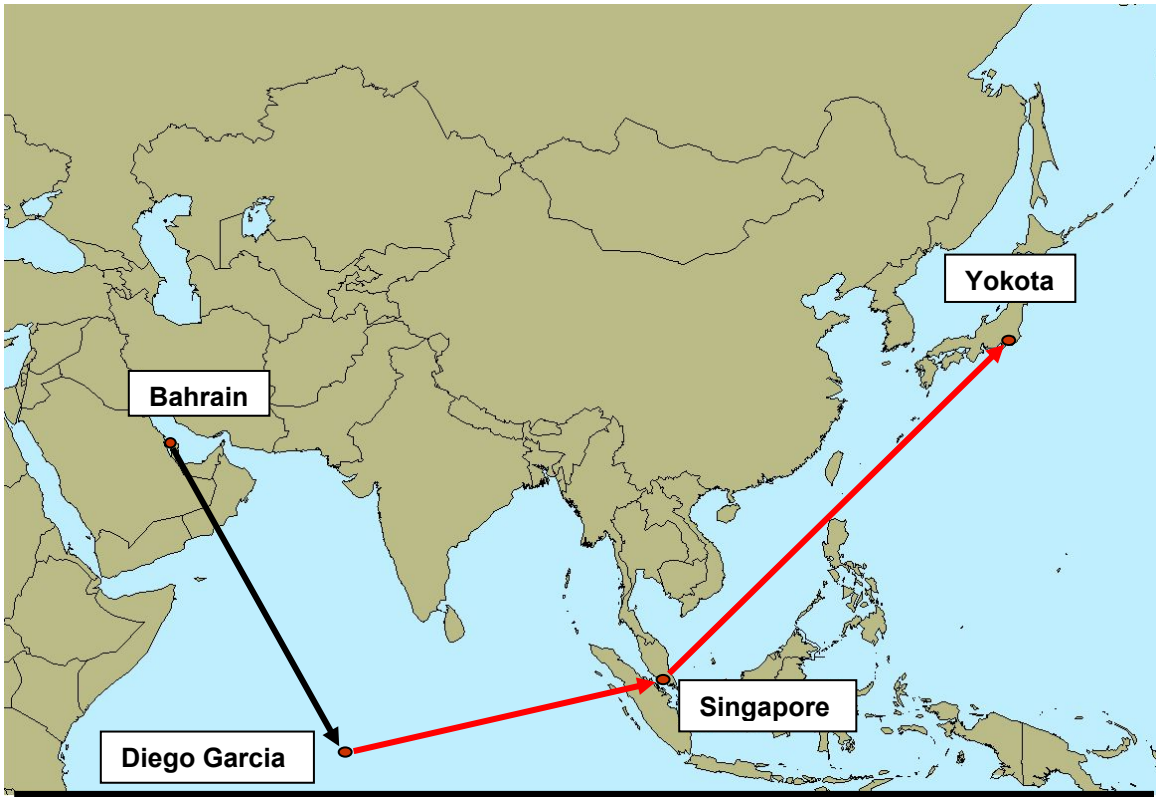


Figure 8: Port (Airfield) Cluster Details

An Air Mobility Mission Re-planning Scenario Using the Timeline Display

We shall now illustrate the Timeline Tool use concept with a scenario framed with respect to a Duty Officer in the TACC. The topical setting is a multi-leg 3 day mission originally scheduled to run from Yokota to Bahrain and back, as shown in Figure 9. In our scenario storyline, this itinerary gets problematical in its final stages.



SORTIE	ETD	ETA	DEP	ARR	PORTS
100	4053:2135	4054:0435	RJTY	WSAP	(Yokota - Singapore)
200	4054:2320	4055:0400	WSAP	FJDG	(Singapore - Diego Garcia)
300	4055:0703	4055:1302	FJDG	OBBI	(Diego Garcia - Bahrain)
400	4055:1525	4055:2115	OBBI	FJDG	(Bahrain - Diego Garcia)
500	4055:2335	4056:0440	FJDG	WSAP	(Diego Garcia - Singapore)
600	4056:0700	4056:1315	WSAP	RJTY	(Singapore - Yokota)

Figure 9: Mission Re-Planning Scenario Itinerary

Our TACC Duty Officer is monitoring a set of missions operating in the South Asia / Indian Ocean region. An incoming call notifies the DO that there is a maintenance delay that has grounded an aircraft at Diego Garcia (end of leg 4 of 6). This maintenance will induce an 8-hour delay before the aircraft can continue (leg 5 of 6, labeled sortie 500). This means the next-to-last leg of the mission (Diego Garcia - Singapore) will be delayed 8 hours.

The DO must explore the ramifications of this pop-up delay and replan the mission as necessary. He / she first selects the record for the affected mission and invokes a detailed Single Mission Display as shown in Figure 10. The display's 'green status' coding means no problems have yet been auto-detected. This reflects the fact that the maintenance delay has not yet been entered into the Global Decision Support System (GDSS), AMC's execution monitoring system. The DO can then initiate a 'simulation mode' in which he/she can manipulate a local copy of the mission's Individual Display to (a) analyze the

new state of affairs, (b) explore its ramifications, and (c) lay out alternative courses of action.

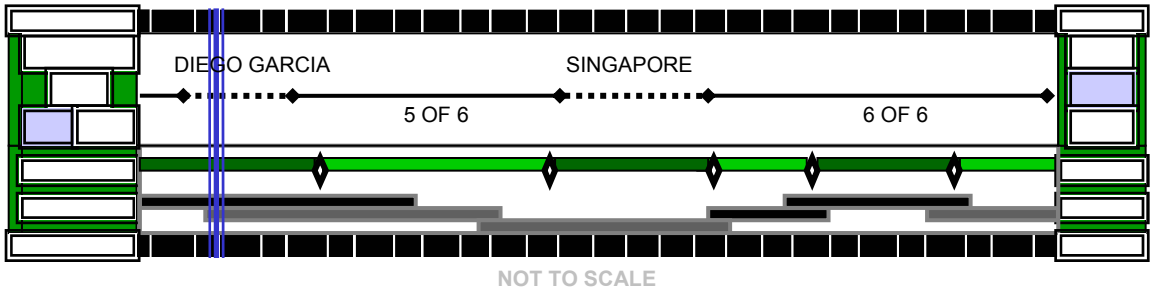


Figure 10: Scenario Individual Timeline

The DO initiates 'simulation mode' and manually modifies the state of the display to reflect a delay of 8 hours in leaving Diego Garcia after the maintenance delay. The DO does this using direct manipulation - 'grabbing and dragging' the Diego Garcia departure time 8 hours later as shown in Figure 11.

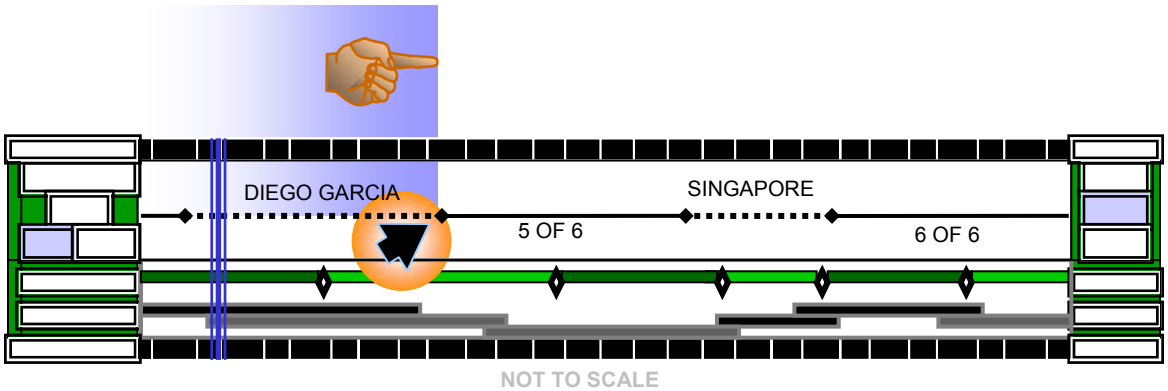


Figure 11: Direct manipulation of mission events to investigate impact

The first re-planning problem

The DO then triggers automated inference aids to project the ramifications of the delay. Figure 12 shows the effect of the delay. Re-computing sortie 500 in light of a simplistic 8-hour 'slide back' reveals a resultant airfield problem for which a new alert indicator is triggered on the updated display. The airfield problem is that the Singapore airfield (WSAP) is currently closed during the middle of the day for construction. The revised arrival time of 1240 is not feasible. It is not reasonable to try and hurry up the maintenance work to get there any earlier. WSAP will be open for accepting new arrivals at 1600. Automated alerting on the new set of circumstances turns the core display red indicating a time violation and displays the affected cluster as shown in Figure 12.

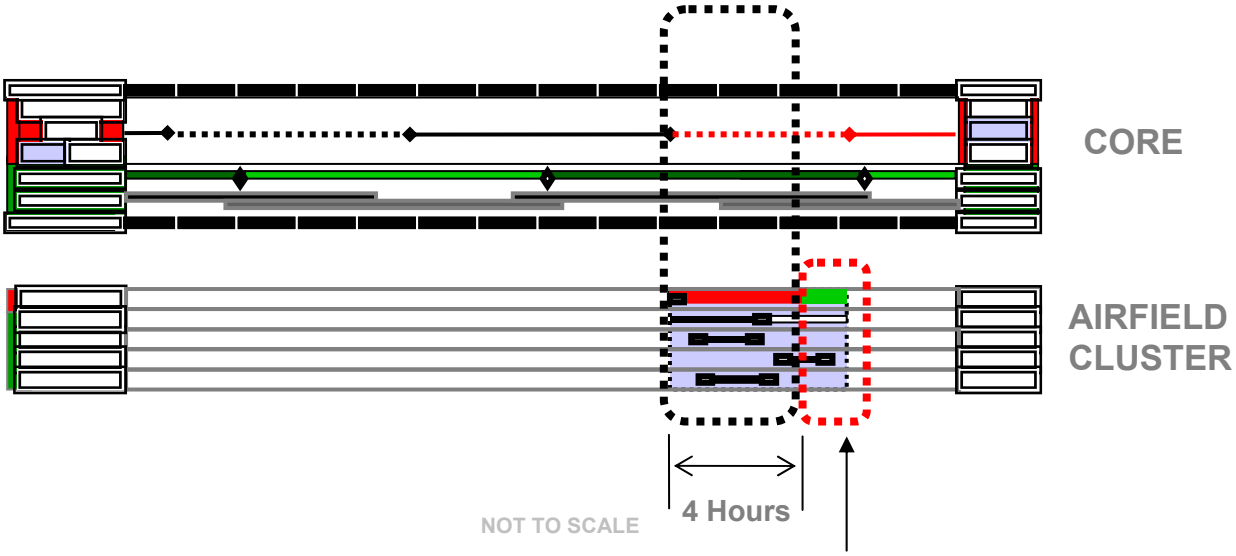


Figure 12: Airfield Cluster Visualization with Alerting

The display clearly provides an indication of duration of the problem condition and "suggests" a solution, in the sense it helps the DO to determine how much longer the mission should be delayed to avoid the airfield closure. The DO determines an additional 4 hour delay will get the aircraft into Singapore after its re-opened and decides the solution is to delay takeoff from Diego Garcia for an additional 4 hours (i.e., 12 hours later than prescribed in the original flight plan). This gives the maintenance people an additional 50% overhead on their projected work time and gets the plane to Singapore some 40 minutes after the airport reopens (hopefully avoiding the initial 'rush' that's certain to occur).

A second re-planning problem

The DO manipulates the display to reflect an additional 4-hour delay in taking off from Diego Garcia. Re-computing sortie 500 in light of this revised plan reveals yet another problem. A new alert indicator is triggered on the updated simulation display as shown in Figure 13. The representation for the leg between Diego Garcia and the Singapore is returned to black, indicating everything is OK for that part of the mission. However, the leg between Singapore and Japan has become red, indicating a problem remains. The problem is associated with a DIP clearance during the period the mission is now scheduled to overfly the Philippines. The lower part of the simulation display gives cues to the problem and provides actionable information to support its possible resolution.

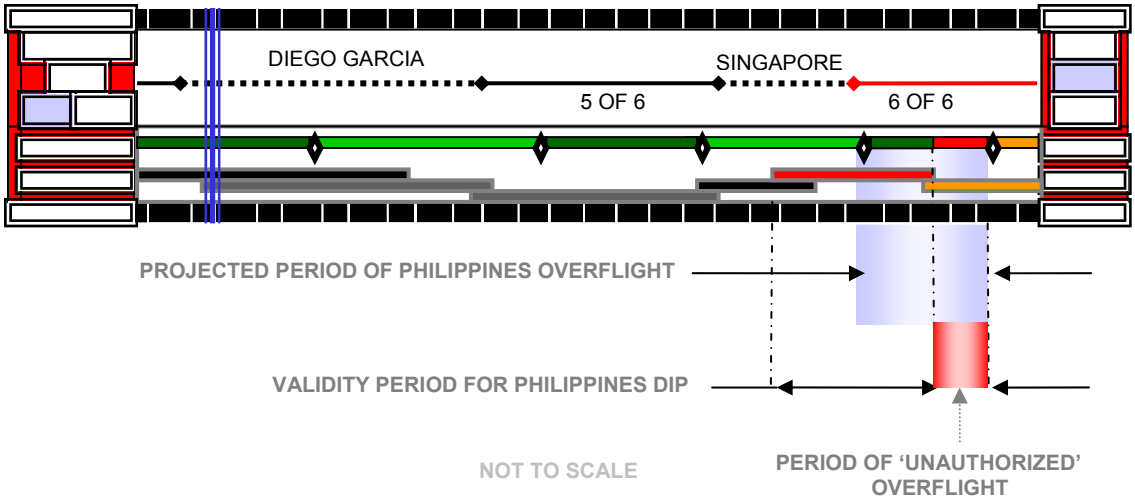


Figure 13: DIPs Visualization with Alerting

The now-12-hour cumulative delay will result in the previously obtained DIP clearance for the Philippines being invalid for the timeframe during which the flight is now projected to overfly that country. The Philippines DIP clearance was originally good until 2000 on day 4056. As clearly indicated in the timeline display, the DIP now needs to be revised to allow overflight several hours later on the same day. The exact amount of extra time required is readily apparent on the display, so the DO has the needed information to fix the DIP problem.

The DIP Clearances are handled by another unit in the TACC external to the DO's Execution Cell. This visualization can serve as an excellent collaboration mechanism depicting the problem and potential solution in a form that can be shared between the DO and the DIP Clearance office. The DO saves the state of this most recent DIPs visualization for his / her own later reference and forwards it as documentation supporting a request for modified or new DIP.

Summary and Comments

Our evolving WCSS concepts and WCD methodology produce elegant design concepts for effectively supporting cognitive aspects of C2 work activities. In the course of this paper we have introduced our approach and illustrated its benefits with respect to our most recent C2 mission planning and execution work aid -- the Timeline Tool. We have also demonstrated how this WCSS concept facilitates effective decision making by enhancing visibility of mission-critical decision factors, portraying key relationships between mission plan elements and constraints, and alerting users to problematical conditions in the work context. By giving users the ability to interactively generate and test alternative course of action, the Timeline Tool reduces the current cognitive and procedural costs of dynamic re-planning. By utilizing a coherent representation, it provides a basis for uniform documentation to be shared with other relevant TACC team members.

Although our example was exercised in a re-planning scenario, the timeline tool has applicability throughout the transport C2 enterprise. It can also be used to develop initial mission plans and to perform pre-launch scrubs of mission plans, etc. Further, we do not believe our approach and its potential benefits are limited to the transport C2 domain. With a moderate amount of KA and re-design, these techniques for displaying mission data can be applied in other C2 domains, such as tactical mission planning. For example, our concept of a modular core and cluster structure for a timeline display may be an effective way to support visualizing strategic and/or tactical C2 mission planning work.

AFRL's WCSS work will continue on both the theoretical and practical fronts. On the theoretical front, we will continue to mature the WCD methodology and investigate the re-use of our WCSS designs. We have observed recurring themes in the form of our WCSS visualizations to date. Such themes are referred to as User Interface (UI) Patterns in the literature (Borchers, 2001) and are starting to see application in C2 (Osga, 2004). A goal of the UI pattern research is to provide a library of key domain specific human-computer interface design templates that other UI designers in similar domains can use as a starting point for C2 system development. Ultimately, this research may lead to re-usable pieces of code to support rapid re-use. For a detailed discussion of the recent views and directions on UI pattern research in this area, please see Stanard, *et al*., 2005.

On the practical front, we are in the process of developing a software prototype that exemplifies the timeline display concepts we have presented in this paper. We will be performing operational evaluations of these WCSS designs beginning in 2005. These evaluations will help us determine the value of the displays in supporting the cognitive aspects of the target C2 work. Our current research plan is to perform a spiral increase in capability, building on the proven techniques, and culminating in a TACC wide demonstration in 2008. Future research and development will involve multiple mission views on both the timeline and geo-spatial displays. We plan to extend WCSS support to senior management to better support fleet wide decisions and to better synchronize workflow and coordination among the TACC team.

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