DESIGNING DECISION SUPPORT FOR MISSION RESOURCE RETASKING

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Command and Control (C2) operators too often need to find and mentally fuse data distributed across multiple sources to accomplish their work. We have been developing and applying work-centered design methodologies to develop advanced visualization and support tools intended to more effectively support C2 cognitive and collaborative work. This paper describes a work-centered visualization aid, called ReCaD, that we developed to support dynamic resource re-allocation during execution in a C2 airlift service. The project illustrates how work-centered design progresses from knowledge acquisition through analysis and design to development and evaluation, with particular attention focused on the cognitive requirements of and demands upon the focal decision maker.

Introduction

Command and Control (C2) operations typically depend on information systems that require operators to find and mentally fuse disparate data distributed across multiple tabular displays in order to accomplish their work. A challenge for the Cognitive Systems Engineering community is to develop and disseminate effective methods for designing support systems that are more finely tuned to the cognitive and collaborative requirements of C2 work.

We have been pursuing a series of projects leveraging cognitive engineering and other bases to develop and deploy *work-centered support services (WCSS)* for airlift C2 decision makers through a process termed *work-centered design* (Eggleston and Whitaker, 2002; Eggleston, 2003; Scott, et al., 2005; Wampler, et al., 2005; Roth et al., 2006).

The work-centered design (WCD) approach emphasizes acquisition and analysis of work domain knowledge to (1) identify key tasks requiring supportive intervention, (2) discover critical aspects of each such task, and (3) create visualization and control features tailored to facilitating the task from the decision maker's point of view. WCSS designs reflect both (a) the task's focal and peripheral data as typically engaged by the decision maker as well as (b) the action affordances requisite to performing the work's constituent activities.

This paper illustrates and discusses the WCD process as it has unfolded in our most recent project for an airlift service organization. This project's focus was on providing more effective cognitive support for identifying and evaluating aircraft resources for potential re-tasking to meet previously-unplanned requirements.

Overview of the Context of Work

The military airlift organization is an air operations center (AOC) responsible for planning, scheduling and tracking of airlift and air refueling missions worldwide. Twenty-four hours prior to a planned mission launch, responsibility for the mission is transferred to the Execution Cell, which is then responsible for handling any last minute changes and problems that might arise during mission execution.

Handling last minute changes is a complicated activity that must take into account issues such as balancing competing airlift demands; ensuring diplomatic clearances for landings in and over-flights of foreign nations; considering airfield, cargo and aircrew constraints; and providing for aircraft refueling requirements (e.g., in-air refueling).

The WCD team has been studying the organization and activities of the Execution Cell and developing WCSS for them since 2004. The first WCSS was a timeline graphic intended to support Execution Cell personnel in handling mission delays (Wampler et al., 2005). A mission delay can create problems such as arriving at airfields when they are closed, expired diplomatic clearances for crossing country borders, exceeding the allowable crew duty day for the flight crew, etc. The timeline display was intended to support Execution Cell personnel in detecting and correcting these types of problems. A prototype was developed and evaluated in 2005 (Roth et al., 2006).

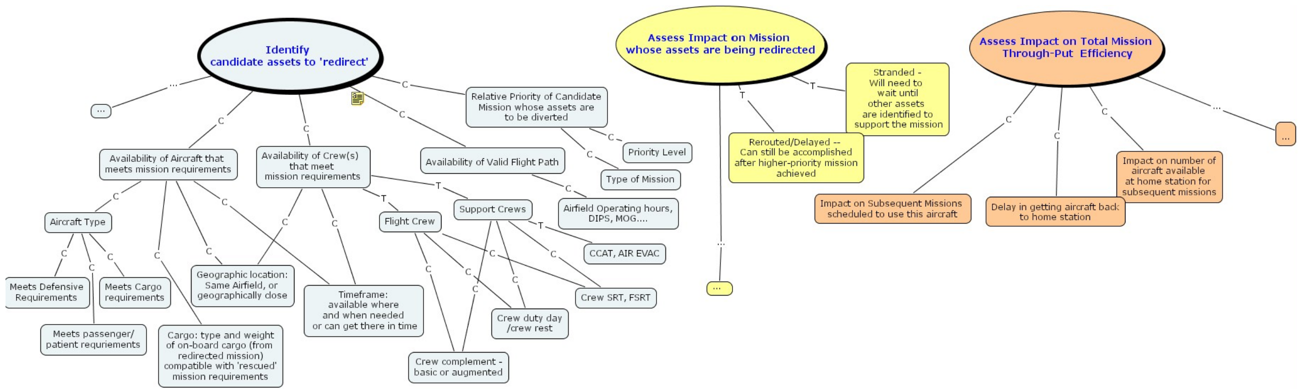

Figure 1. Selected factors that enter into dynamic replanning and resource reallocation decisions.

The prototype timeline was shown to produce significant improvement in task completion time, errors, workload and situation awareness when compared to existing C2 information systems.

Starting in 2005 attention shifted to the question of how Execution Cell personnel address new *pop-up* requests that require dynamic replanning. Examples include aircraft malfunctions requiring a re-allocation of resources to support a high priority mission and aeromedical evacuation (AE) cases that involve urgent patients that need to be evacuated by air within a short time period.

An analysis of work domain demands and decision requirements was conducted based on interviews and observations of Execution Cell personnel in their work environment. Knowledge acquisition activities included:

- shadowing Duty Officers (DOs) and AE personnel responsible for identifying candidate resources that can be redirected to meet pop-up mission;
- interviewing 'Seniors' (senior officers within the Execution Cell) responsible for prioritizing requirements and approving dynamic re-allocation of resources;
- interviewing DOs and AE personnel to elicit examples of past dynamic re-allocation situations that have arisen and the factors they have considered in making re-allocation decisions;
- collecting written descriptions of actual past critical incidents;
- observing DOs and AE personnel work through representative cases under controlled conditions.

Results revealed that dynamic reallocation decisions arise on a daily basis. DOs indicated that there can be several missions a day that need to be 'rescued'. AE personnel indicated that they generally saw one to five unscheduled AE mission requirements a day. Further, re-allocation decisions are complex, involving consideration of many factors. Figure 1 depicts some of the factors that enter into the decision making process. Considerations include:

- *assessing pop-up mission requirements*: What type of aircraft is required? How much passenger/cargo space is required? What is the time-window within which the mission needs to be performed? Are there any special restrictions on flight crew or flight routes? Will diplomatic clearances be required?
- *identifying suitable candidate resources:* What aircrafts are scheduled to pass through or near the '*focal port'* (i.e., the airfield where the aircraft is required) that meet mission requirements? Is there room to take on the pop-up mission passengers/cargo?
- *assessing the relative priority of the missions:* How high of a priority is the pop-up mission relative to the mission whose resources would be re-allocated (referred to as the *original mission*)? Is the candidate resource '*steal-able'*? What type of mission is it? What passengers/cargo are currently onboard the aircraft and where/when are they scheduled to be dropped off? What are the consequences in terms of delays or inability to meet the objectives of the original mission or any follow-on missions that were planned for the aircraft being redirected (referred to by users as '*broken glass')*? Can the original mission be diverted to accomplish the pop-up requirement and still meet goals of the original mission and planned follow-ons? Are there alternative ways to meet the goals of the original mission (e.g.,

other missions that can be used to accomplish those goals)?

- *dynamically coming up with a mission plan:* What flight route will be required? Will diplomatic clearances or permissions be needed? How long will the mission take? Will a refueling stop or in-air refueling be required? Can the mission be accomplished within a crew duty day or will a crew duty day waiver or fresh crew be required? Will the aircraft arrive at an airfield during closed or quiet hours? If so, is a waiver likely to be obtainable? Will there be slots available at the airfield when it needs to land, and if not, is it possible to 'bump' other missions that are scheduled to land at that airfield at the same time?

The information systems currently available do not effectively support C2 personnel in making these dynamic reallocation decisions. While much of the relevant data for understanding the flight plan are available in the information system, the user needs to navigate across multiple tabular displays to extract and mentally collate the necessary information (see Figure 2). For example, in order to identify a candidate aircraft that could be re-allocated to the pop-up mission, the DO needs to pull up station workload displays that list aircraft that will be landing/taking off from a specific airfield. If there are no appropriate candidates at the focal airfield, the DO must pull up displays for other airfields in the vicinity, and review them one at a time. No support is provided for easily identifying which airfields are in the vicinity; the DO must rely on his/her own knowledge (or ask others). Further, not all required information is available in the current information systems. Some of the relevant information must be obtained from other sources such as web-based tools. For example there are web-based tools that provide information on missions offering unused capacity that could be exploited. There are also web-based tools that list aircraft with different specialized capabilities such as aircraft with special 'electronics/communication' packages. Other critical information such as details on passengers and cargo onboard the candidate aircraft must be obtained by contacting the airfields directly. The burden of obtaining and integrating these additional sources of information to support reallocation decisions currently falls on the DO.

The results of the analysis pointed to a need for improved cognitive support for identifying and evaluating aircraft resources for potential re-tasking to meet previously-unplanned requirements.

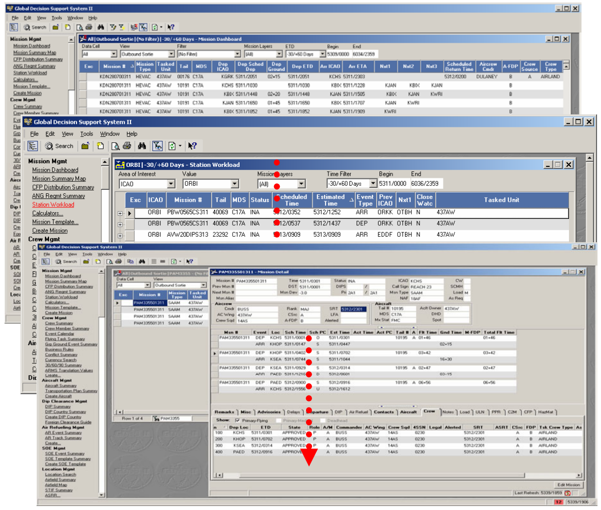

Figure 2. Examples of existing information system tabular displays.

A number of opportunities for more effective work-centered aiding were identified, including:

- creating an integrated display that would allow users to consider a larger set of candidate resources (across multiple airfields) that are capable of meeting the pop-up requirement (so that DOs would be less likely to miss viable options);

- providing ready access to relevant mission details (aircraft, crew, cargo, mission objectives, schedule, priority) associated with each candidate resource to enable users to focus on the subset of best candidates both from the perspective of:
  - meeting pop-up mission requirements;
  - minimizing potential for 'broken glass' (with respect to original mission and planned follow-ons);

- providing 'what if' capabilities that would allow the user to 'add/delete/modify' legs of the original mission so as to be able to evaluate the viability of the proposed revised plan intended to support the new pop-up requirement.

The ultimate goal is to create a WCSS that would enable DOs to make better decisions (i.e., better choices as to which resource to redirect) in the sense of selecting the course of action that better meets requirements of the pop-up mission being supported while creating minimal 'broken glass'.

ReCaD Prototype

We designed a prototype WCSS to provide more effective cognitive support for dynamic replanning to meet pop-up requirements. This latest WCSS design is referred to as the *Resource Candidate Display (ReCaD*). ReCaD interweaves visualization and search support for distinct temporal, geospatial and 'logical' dimensions of the decision space. It includes a tabular presentation of candidate resources (i.e., aircraft currently supporting other missions that could be used to support the pop-up requirement), a coordinated map that shows the geographic location of the candidates, and an expanded timeline visualization that builds on the timeline display developed in an earlier design spiral that enables individuals to examine mission details and explore ramifications of redirecting resources to support the pop-up requirement (e.g., by adding, deleting or modifying flight legs).

Candidate Resource Tabular Display

The candidate listing tabular display allows a DO to rapidly gather a set of candidate aircraft that are currently on other missions that could be redirected to meet the pop-up request (see Figure 3). The DO enters the focal airfield of interest (i.e., the 'origin' location where the aircraft needs to be for the pop-up requirement), the type of aircraft required, a distance search radius, a time window within which the aircraft needs to be at the focal airfield, and (optionally) an indication of the destination ('to') airfield (i.e., where the pop-up requirement passengers or cargo need to be taken to). A search then generates a listing of candidate aircraft that meet these requirements. The candidates returned are ordered by 'earliest possible arrival time' at the focal airfield.

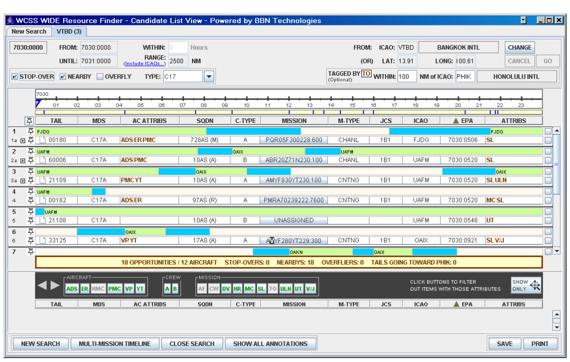

Figure 3. Candidate Resource Tabular Display.

One advantage of this display is that it allows the DO to simultaneously search across multiple airfields in a given geographic region by specifying a distance search radius around the focal airfield of interest. Thus, unlike when using current tools, the DO is not limited to searching one airfield at a time. In addition, he/she is not required to know what airfields are in the geographic vicinity that might have promising candidates.

The tabular display includes relevant mission detail information (crew and aircraft properties, selected cargo information, mission priority) associated with each candidate aircraft. This enables users to focus on the subset of candidates most likely to meet pop-up mission requirements and minimize 'broken glass' (with respect to original mission and planned follow-ons). Each entry also graphically depicts the candidate's in-air and on-ground periods – enabling users to assess temporal windows of opportunity for diverting the resource. DOs are able to eliminate candidates from the display based on selected attributes (e.g., if it is carrying important passengers or human remains; if it has equipment malfunctions) as well as a 'show only' function that allows them to limit search results to missions with a particular attribute (e.g., aircraft that have specific electronics/communication packages; aircraft that are already scheduled to go to or near the 'to' destination airfield). They can also move a pointer on a time scale at the top of the candidate list to refine the temporal search window.

Map Display

A coordinated map display appears in parallel with the candidate resource tabular display (see Figure 4). It provides a geographic view of the location and planned routes of the resource candidates listed in the tabular display. A visual indication of the distance search radius is also shown. This complementary view allows DOs to evaluate candidates based on visual inspection of their location and planned routes.

The map display also allows the DO to inspect the candidate mission itineraries in more detail. Clicking on a resource candidate in the tabular display brings up a detailed itinerary view on the map display (See Figure 5). An itinerary schematic appears at the top of the map that shows the itinerary and schedule for the current mission and any planned follow-ons for the candidate aircraft. An aircraft icon indicates where the aircraft is currently. By hovering over airfield nodes in the itinerary schematic the DO is also able to get more details on the mission such as the purpose for each stop (e.g., onload, offload, refuel). Inspection of the itinerary schematic cues the DO to objectives and priority of the current mission

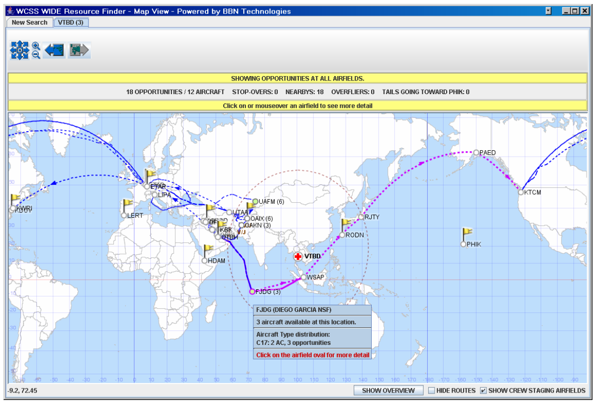

Figure 4. Screenshot of Map Display

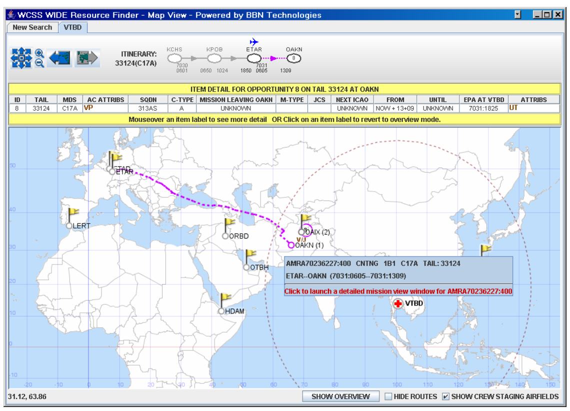

Figure 5. Detailed itinerary view on map.

and planned follow-ons to aid in estimating the likely impact, in terms of 'broken glass', of redirecting this candidate aircraft to meet the pop-up requirement. This view provides an additional tool for rapidly evaluating potential candidates and focusing in on the most promising ones.

Timeline Display

The timeline display that we developed in an earlier spiral was adapted to allow users to drill down to examine a candidate in more detail, and to perform 'what if' analyses to explore more deeply the potential consequences of redirecting resources associated with a selected candidate to accomplish the pop-up requirement.

The timeline display allows Execution Cell personnel to "see at a glance" the relationships between mission plan elements and planning constraints. Integrated alert cues highlight constraint violations and guide problem-solving. The display presents the elements of a mission (origin and destination, scheduled departure time, intermediate stops, air refueling, etc.) visually correlated on a timescale (see Figure 6). Relevant factors and time-correlated constraint windows are organized into "clusters" (e.g., airspace, aircrew, ground activity, load, airfield) and presented graphically. Constraint violations (e.g., reaching an airfield when it is closed; violating crew duty day limitations; violating diplomatic clearance time windows for overflying a country) are displayed graphically as well as via text messages at the bottom of the screen.

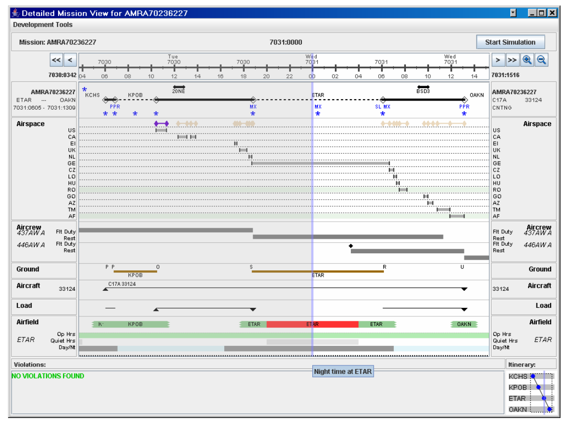

Figure 6. Detailed mission timeline. A vertical 'now' line distinguishes past events (shaded area) from planned future events.

A 'what-if' mode allows the user to make changes to the mission plan via direct manipulation. Any planning constraints that are violated trigger an alert. The user can then make further simulated changes until a workable course of action is found that will lead to a viable plan.

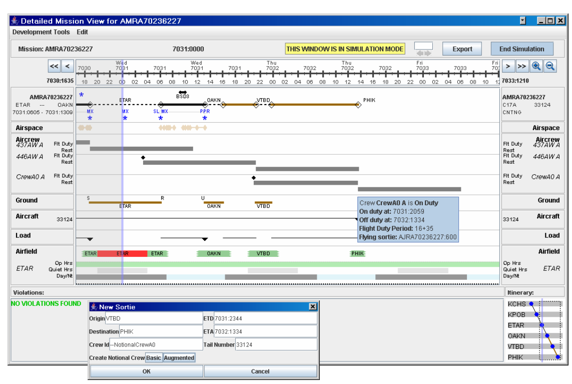

Figure 7. Screen shot of a mission timeline display in 'what if' mode showing two new legs being added. As part of the ReCaD effort this 'what-if' capability

was expanded to allow users to add, delete and/or modify legs and specify crew changes in order to assess the viability of redirecting a candidate resource to meet a pop-up requirement (see Figure 7). Any constraint violations that result from these route changes are flagged. In this way users are able to evaluate whether a viable mission plan can be developed to support the pop-up requirement using a given candidate aircraft as well as whether the aircraft can then go on to accomplish the original and follow-on mission objectives.

Evaluation

Ten current DOs and two current AE personnel participated in an evaluation of ReCaD. Participants received two hours of training followed by presentation of four 'hands-on' scenario exercises to solve using ReCaD. Performance with the ReCaD prototype was compared to 'baseline' performance that was collected a month earlier on similar scenarios using the actual real-time information systems employed by the Execution Cell. While no objective improvements in performance were observed, post-exercise questionnaires filled out by the study participants indicated strong positive opinions of the likely benefits of the ReCaD tool.

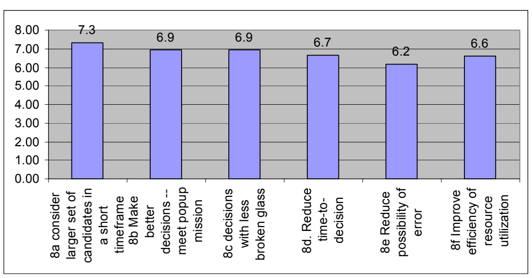

Figure 8. Mean rating scores on post-exercise questionnaire (on 8 point rating scale, 8 = extremely effective).

As shown in Figure 8, mean questionnaire ratings indicated that participants felt ReCaD would enable them to consider a larger set of candidates in a short time and improve quality of decisions. These responses establish that participants felt that ReCaD achieved its performance improvement objectives. We are currently in the process of improving the usability and usefulness of ReCaD based on evaluation results and user feedback.

Conclusions

This project provides an illustrative example of how WCD progresses from knowledge acquisition through analysis and design to development and evaluation with particular attention to the cognitive requirements of and demands on the focal decision maker. The longer term research objective is to abstract from specific design successes to develop and disseminate more effective methods for designing support systems that are finely tuned to the cognitive and collaborative requirements of C2 work.

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