ENVISIONING EVOLVABLE WORK-CENTERED SUPPORT SYSTEMS: EMPOWERING USERS TO ADAPT THEIR SYSTEMS TO CHANGING WORLD DEMANDS

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Work-Centered Support Systems (WCSS) provide visualizations that reveal domain constraints and affordances based on software agent technology to support cognitive and collaborative work. Here we argue for a need to incorporate facilities that enable users to adapt these systems to the changing requirements of work—e*volvable work-centered support systems.* We recently developed a WCSS for weather forecasting and monitoring in an airlift organization that is currently used in their operations center. As part of the development process we conducted field observations both prior and subsequent to system introduction. A striking finding was the constant changes that operations personnel faced (changes in goals and priorities; changes in scale of operations; changes in team roles and structure; changes in information sources and systems). We describe the changes in workplace demands that we observed and the modifications we needed to make to the WCSS in response. Our findings are presented as a case study to illustrate the challenges confronted in designing a WCSS to support a constantly changing environment. For today's fielded systems, making changes that are responsive to users changing requirements in a timely manner is seldom possible.

INTRODUCTION

Over the past several years we have been developing work-centered support systems (WCSS) to aid mission planning and Command and Control in a military airlift service organization. WCSS are designed to provide comprehensive support for the multiple aspects of work (e.g., decision support, product development support, collaborative support, and work management support) within an integrated work-oriented framework (Eggleston, 2003; Eggleston and Whitaker, 2002; Eggleston, Roth and Scott, 2003). Our first system, called Work-Centered Support System for Global Weather Management (WCSS-GWM) was developed to support weather forecasting and monitoring and is currently installed and in use in the airlift service organizations' operations center (Scott, Roth, Deutsch, Malchiodi, Kazmierczak, Eggleston, Kuper and Whitaker, 2002). More recently we have expanded our analysis and design activities to cover the larger airlift mission planning and execution process (Wampler, Whitaker, Roth, Scott, Stilson and Thomas-Meyers, 2005).

As part of the work-centered design process we had the opportunity to perform field observations and structured interviews with weather forecasters, flight managers (FMs) and command and control personnel over a span of four years. Field observations were conducted both prior to development of our initial design concepts so as to ground the design in the field of practice, as well as after the initial system was deployed (toward the end of the second year), so as to insure that elements of work that were unanticipated and not well supported would be uncovered and addressed. During the course of our study we observed a wide range of changes that impacted cognitive and collaborative work in the operations center.

We describe the changes that we observed, the informal artifacts that users created, and the requests for modifications to the WCSS-GWM that users made, in response to these changing demands. Our findings are presented as a case study to illustrate the challenges confronted in designing a WCSS to support a constantly changing environment. The results point to the need for software systems that can evolve to adapt to the inevitable unanticipated changes that arise in the world. We coin the term '*Evolvable Work-Centered Support Systems'* to describe the adaptable systems we envision and point to some promising software directions for achieving that aim.

TECHNICAL APPROACH

We conducted two analyses to understand the kinds of changes that occurred in the domain and the impacts they had. One analysis examined the kinds of work-arounds and informal artifacts developed by the user community to compensate for inability of existing software systems to accommodate operational changes. The second analysis examined the change requests that were submitted to the WCSS-GWM software design team by the user community in response to changes in work demands. Examination of the results of these two analyses highlight the need for evolvable work-centered support systems, and point to the kinds of capabilities that evolvable work-centered support systems need to display.

ANALYSIS I: USER STRATEGIES FOR COPING WITH A CHANGING WORLD

We conducted field observations and structured interviews in the operations center over a four year period. The first year was largely devoted to initial understanding of the domain, the systems supporting the present day work flow, and exploration of the possible Work-Centered Support Systems that might be implemented. The WCSS-GWM system was designed, implemented and installed during the second year. Feedback from users guided the refinement of the system over the third year, as the system was completed. A fourth year has elapsed during which time we have conducted additional observations and interviews in the command and control operations center as part of an ongoing program to expand the work-centered support for command and control staff (Wampler, et al., 2005). Field visits occurred approximately every three months during the four year span of the project and were of two to three days duration each.

The work environment of the airlift service organization did not remain static over the four year period of observation. Among the changes observed included:

- changes in goals and priorities of the work (e.g., the nature of flight missions that were conducted; the parts of the world where missions operated);
- changes in scale of operations;
- changes in roles, team and organizational structure;
- changes in complexity of problems faced (as number of missions increased the airlift service organization hit against hard resource constraints making it more important to anticipate and respond to resource bottlenecks and prioritize among missions in cases of goal conflict);
- changes in information sources and information systems provided to support work;
- and changes in the physical layout of the operations center (the operations center was remodeled with the result that forecasters and FM were no longer in as close physical proximity).

While some of the changes were anticipated, others were not. Further, even in the case of anticipated changes, their impact on team roles and work structure were not necessarily foreseeable.

One of the most striking changes was in scale of operation. As work on the WCSS-GWM program was starting, in February 2001, the position of FM was just being created and staffed. The FMs were only assigned a small percentage of the flights handled by the Command and Control Operations Center of the Airlift Service Organization. Initially, there was an average of three FM per shift and FMs handled less than 20 flights a month. By February 2004 there was an average of 10 FM per shift and FMs handled more than 3000 flights a month.

At the time that the WCSS-GWM was being developed, the organization anticipated, and informed us, that there would be a dramatic increase in the number of missions that would need to be handled, and a corresponding increase in staffing. However, while they anticipated an increase in scale, the management of the organization had not determined what changes would be needed in organizational structure to accommodate the increased number of missions. The new organizational structure that was eventually adopted could not have been foreseen ahead of time.

With the increase in scale there turned out to be a shift in team member roles and tasks. While initially a forecaster worked one on one with a flight manager to produce a tailored forecast for each flight managed mission, the nature of the collaboration between forecaster and flight manager changed as the number of FMs and flight managed missions increased. There became three separate forecaster positions, one position generating forecasts for different geographic regions, one monitoring 'high risk' missions and one responsible for monitoring the remaining lower risk missions.

Among the consequences of the various changes we observed was a growing mismatch between the support provided by the information systems in place, WCSS-GWM included, and the requirements of work.

Because the WCSS-GWM was an R&D effort, the development team was in a position to rapidly respond to change requests. In contrast, even simple user change requests to legacy systems required lengthy lead times on the order of months to years to satisfy. As a consequence, we observed users turn to development of informal artifacts including 'home-grown' software to compensate for system – work mismatches.

Over the course of our field observations we identified a number of cases where informal artifacts were created to compensate for the limitations and rigidity of existing information systems. These took the form of:

1. Physical artifacts such as handwritten cheat sheets and sticky notes;
2. New visualizations that graphically depicted important information that was not provided by the information systems as designed;
3. 'Local' databases that stored updates and corrections to information stored in the formal system data bases;
4. New software tools programmed by members of the user community to create support systems for aspects of work that were not well supported by the formal information systems.

The emergence of locally developed software artifacts such as new visualizations, local databases and 'home-grown' software tools was particularly noteworthy as these types of user-developed 'artifacts' have not been as widely documented in the prior literature. They provide salient examples of the creative, and increasingly sophisticated, work-arounds that users employ to compensate for mismatches between rigid software tools and the evolving demands of work. They point to the importance of developing systems that can be more readily modified by users to support their work.

ANALYSIS II: WCSS-GWM CHANGE REQUESTS

Examination of change requests to the WCSS-GWM provided a second window into the need for more adaptive systems to keep pace with evolving work requirements. We identified fifty requests for changes to the WCSS-GWM that were made by the user community. These change requests were classified according to (1) the underlying reason for the change request, and (2) the impact on the supporting software to accomplish the change request.

The goal of the exercise was to understand which change requests resulted from changes in the context of work that could not have been anticipated ahead of time, and to provide a characterization of types of software changes they entailed. Examination of the kinds of software changes that were motivated by changes in the world provided insight into the kinds of mechanism for change that need to be provided in evolvable work-centered systems to enable users to adapt the systems to the changing nature of work.

Table 1 summarizes the classification of WCSS-GWM system change requests based on the reason for the request. The majority of system change requests (68%) arose from changes in how the system was used, changes in work processes, organizational changes, changes in systems it communicated with, and other environmental changes.

One of the most common reasons for a change request was expansion of the role of the WCSS-GWM within the organization – either its use by a new category of user, or by expanding the use by an existing user into a new area of work. Another common reason for change was environmental change: some externally-triggered alteration in data availability, hardware, or software that induced new constraints on or offered new opportunities to the WCSS-GWM. These types of changes could not be foreseen during the original design process.

The second classification of system change requests was based on the type of software change it required. We classified change requests into four broad categories of software impacts – Data Acquisition changes, Automated

Reason for Change Request	Number of Change Requests	Comment
New user	11	Additional types of users resulted in expansion of the envisioned uses for the aid.
New use	6	Original type of user, but expanded scope of use.
Unanticipated model of use	3	Original type of user and scope of use (what they would use it for), but unanticipated model of use (e.g., when and how they would use it)
In queue	10	Anticipated functionality on the 'queue' of features to be eventually implemented, implemented as resources allowed
Environmental Change	10	Changes in hardware, software, data availability that impose new constraints or create new opportunities
Uncovery of Requirement	2	Uncovery of an existing requirement that was not picked up earlier (e.g., due to KA sampling limitation)
Change in work process	2	Change in the process by which work is conducted.
Organizational change	1	Change in the structure of the organization, change in how work is allocated across individuals and groups
Correction	1	Correction of a system problem
Design Improvement	3	Improvement of design, based on user feedback/testing
Organizational conflict	1	Reconciliation of disagreement between user organizations

Table 1: Reasons for WCSS-GWM Change Requests

Analysis changes, User Interface (UI) changes, and Software Infrastructure changes. The results are shown in Table 2. Some of the change requests, such as the ones that involved software infrastructure changes, required significant software modification. These types of changes are best handled the traditional way, with software engineers making the changes and delivering an updated product at a later time. On the other hand, a significant number of system change requests resulted in simple UI changes (adding new data to an existing display) and/or straightforward Data Acquisition changes – adding a new data source. The impact of designing a Work Centered Support System that could easily accommodate these changes by the end-user organization would be high.

TOWARD EVOLVABLE WORK-CENTERED SUPPORT SYSTEMS

The two analyses we performed provided a basis for defining a list of desirable capabilities of an 'evolvable work-centered system'. Each of the items in this list represents one way an evolvable system would be able to be changed, without resorting to bringing in programmers to implement the changes. Capabilities include:

- *Bringing new data into the system.* Many of the change requests we saw involved making new data available to the user.
- *Adding new data to an existing display.* Once the data is accessible to the system, it needs to be made visible to the user in an appropriate way.
- *Receiving existing data from a new source.* One of the most common change requests we've seen related to a change in data source.
- *Altering the way data is presented in an existing display.* Changing how data is presented in a display (e.g., color and symbology) is actually one of the easier types of system changes to accommodate. Many existing C2 systems already allow their users to customize their displays in this way.
- *Reviewing and altering transformation and filtering rules.* Each of the decisions made by these rules must be understandable and transparent to the users of the operating organization.
- *Reviewing and altering the behavior of the presentation module.* The behavior of the presentation module must be understandable and easily modifiable.
- *Allowing integration with 'homegrown' tools/artifacts.* As users in the operating organization get more technically sophisticated, they begin to build spreadsheets and text files of information that is not available in their standard systems. Software should allow easy integration with such user-defined tools.

Category of Software Change	Subcategory	Number of Changes
Data Acquisition		
	Acquire new data	9
	Change source/format for existing data	3
Automated Analysis		
	Add new analysis agent	6
	Add new processing module for use by an agent or GUI	6
	Modify rules of existing analysis agent	1
User Interface		
	Add new data to existing display	12
	Change how data is displayed	3
	New type of display	2
	New functionality	10
	Reorganization of GUI elements	4
Software Infrastructure		5
note: some changes require more than one category of software change		

Table 2: Software Impacts of WCSS-GWM Change Requests

- *Supporting 'local override databases'.* By explicitly allowing for a 'local override database' – a user-controlled database of critical knowledge they have that overrides standard data – our evolvable work-centered systems can make use of the detailed knowledge of the local experts.
- *Supporting test and validation.* Providing test suites to facilitate validation of software changes.

GENERAL DISCUSSION

A number of researchers have noted that users will informally tailor the design of their systems and work practices to better meet the local demands of the situation. This has been referred to as 'finishing the design' (Vicente, 1999; Mumaw et al., 2000; Vicente et. al., 2001). Vicente (1999) has argued for the importance of creating systems that afford the potential for productive adaptation to enable users to 'finish the design' locally in response to the situated context of work. Our findings and conclusions are consistent with Vicente's proposal. They extend the ideas by emphasizing that the demands of the world are not fixed but will change over time. Thus, 'finishing the design' is not merely a matter of responding to specific local conditions but entails adapting systems so as to keep pace with a constantly evolving world – in that sense the design is never really 'finished'.

While upfront analyses are always limited with respect to available time, resources and access to domain practitioners (Potter, Roth, Woods and Elm, 2000), that does not fully explain the mismatches that emerged over time. The kinds of forces for change that we observed during our study period produced new requirements that could not have been fully foreseen during upfront analyses.

For a system to remain 'work-centered' over time it must not only support the elements of work identified at the design stage, it must also be able to accommodate elements that the initial design did not appropriately capture and be adaptable to meet the changing nature of the work. While spiral development methodologies attempt to meet these challenges, they have proven less responsive than necessary in the environment in which we have been working and in related environments with which we are familiar.

The extent to which our users have contributed their own software solutions to meet the demands of their work clearly suggests that users are ready to step in and help address the demands for more responsive systems. The challenge as we see it is to enable the user community to evolve the software structure so as to be able adapt to the changing demands of the world – *evolvable work-centered support systems.* We believe that such an aim, while technically ambitious, can lead to systems that gracefully evolve to meet changing workplace requirements.

We are just taking the first steps in meeting this challenge: first enumerating the types of change that we have encountered and looking at how the design and software teams have addressed and implemented the changes. As we go forward, we will be looking at which types of changes might reasonably be accomplished by users, and what software tools will need to be constructed to enable the users to make and validate changes. Today, the WCSS-GWM includes many aspects that the current users can tune to meet their needs; we are looking carefully at how this set can be extended with the long-term goal of providing an evolvable work-centered support system.

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