Boundary Objects, Information Flows, and Organizational Memory: Supporting Knowledge Reuse in a High-Reliability Organization

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ABSTRACT
Advanced requirements analysis for improving IT support for knowledge reuse. A thirteen month ethnographic field study of the distributed problem solving behavior of service engineers in a world-class aircraft manufacturer. Examines the boundary objects, information flows and organizational memories which facilitate the routine handling of technical support requests from airlines.

KEYWORDS
Boundary objects, information flows, organizational memory, computer-supported cooperative work, knowledge reuse, qualitative field study, technical support.

SCENARIO (AOG) [1]

Imagine the following scenario that is all too likely: TransGulf Flight 471 to Houston is at the gate. Passengers have just finished boarding, the crew is ready, and the luggage is loaded. As the baggage conveyor is pulling away, the driver accidentally hits the accelerator, ramming the aircraft. A quick visual inspection confirms a dented forward cargo door frame. Two hundred eighteen passengers wait patiently in their seats while the airline's mechanics swarm around the cargo door taking measurements and photographs. The damage is serious enough to require guidance from the manufacturer's technical support department. This is a priority situation requiring immediate attention. "Airplane on ground!"

The TransGulf request is quickly relayed to Global Airframe, the manufacturer. A senior service engineer is already on the phone with the ground crew. She has dropped all other jobs to focus solely on resolving this action. The faxed incident details and images have been digitally processed and appear on her workstation within moments. She quickly reviews the documents, prints them, and stamps the packet crimson, "AOG." Pouring over blueprints, searching databases, consulting bound references and querying local experts, she must come up with an approved corrective action in a matter of minutes. The plane *is* still loaded and sitting at the gate.

The engineers at TransGulf and at Global Airframe know what the problem is, but they need an immediate solution. There is a scurry of activity, in addition to the normal heavy workload, at Global: "Who's the expert on cargo doors for this model?" "Have we seen damage like this before? How did we fix it?" "Does the FAA have an airworthiness directive on it?" "What are the load figures and safety tolerances for the frame?" "Who will verify the numbers, run the stress analysis and sketch the repair?"

While the assembled team of experts is working the problem, the senior engineer, still on the phone with TransGulf, searches the historical record. She finds one relevant case. It is not a perfect match, but the depth and angle are similar. She rushes it over to the team. The record reminds the analyst of other metal fatigue considerations with a dent this deep; speeding their time to a response.

After forty minutes, Global's answer is in: "Remove and replace." The damaged plane is not airworthy. The passengers disembark, waiting in the terminal as gate agents scramble to cover their flights. The airline loses thousands of dollars an hour as the now out-of-service craft taxies toward the maintenance hangar. Nonetheless, a potential disaster has been averted.

RESEARCH PROBLEM

Organizational remembering, information use and reuse, and expertise management are complex and nuanced phenomena [11]. This is exemplified by the behavior of the technical support team described above, as they collaboratively resolve a priority call. While the ability to leverage organizational knowledge is admittedly a critical success factor for most knowledge work [6], our understanding of the social processes which enable such knowledge reuse is impoverished [1].

Most of the organizational memory and knowledge reuse literature has focused on designing systems to support these activities, rather than promoting a deep understanding of the phenomena itself [2]. Within CSCW, there are only a handful of detailed, field-based, empirically-grounded

[1] While all scenarios in this paper have been generalized, they are based on actual cases and accurately represent the types of information flows and reuse typical for their class of routine service calls.

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studies of expertise, reuse and organizational memory (e.g. [5,8,10]). Much remains to be understood. Building upon these efforts, I would like to answer these important questions:

- How do individuals properly distilled information for storage and later use? (*processes of decontextualization*)
- How is that information later successfully discovered, reconstituted and adapted by individuals to fit a problem at hand? (*processes of recontextualization*)
- How do individuals navigate the knowledge network of an organization to find the relevant expertise to perform these tasks?
- How can IT be designed to best support these activities?

In their recent analyses of knowledge reuse in a help center, Ackerman and Halverson [1,2] found customer support organizations to be a rich venue for exploring the use of organizational memory systems. These situations have sufficient routine work to map their information processes; yet, there are always new questions and problems. Technical support work is time critical and extremely information intensive. In addition, support groups are often lead users of collaborative information access technologies.

For the technical support department at Global, the goals are clear. They have a high requirement for reliability,[2] but with growing requirements for turnaround time and price. Furthermore, this situation exists within a complex regulatory and legal liability web, which must be accounted for in the information processes. Finally, there is a constant concern about the public visibility of mistakes. The complex information environment, with its time and reliability pressures, brings out additional dimensions in information reuse, information contextualization, and expertise search.

SITE DESCRIPTION

Global Technical Support (GTS) is the division within Global Airframe which provides technical support for the operators of Global aircraft (e.g. airlines, cargo companies). This support is required of all airframe manufacturers by the Federal Aviation Administration (FAA), but technical support has also been a key selling point for Global Airframe. The GTS division is organized into four semi-autonomous operating units by aircraft models and use (i.e. commercial or military). GTS units are located throughout the United States, but this study focuses on GTS-West.

GTS-West is responsible for an entire family of aircraft models, dating back to the early 1930s. (The FAA mandates that as long as a single plane remains in service, the entire model must be supported.) GTS-West supports over 3,000 in-service aircraft, all of which are post-production, having been manufactured by a merger-partner, International Airframe Corporation (IAC).

The GTS-West staff takes pride in the quality of their work and their industry-wide reputation for service. They are very successful with respect to their key metrics of time-to-response, completeness of answers, and overall customer satisfaction. They can accomplish this with limited staffing and resources because of two inter-related factors. The first is the highly generalized knowledge of the workforce as well as the GTS-West engineers' ability to leverage the information in their environment to augment their personal expertise. (Unlike the tight specialization common in the industry, all GTS-West engineers are expected to work outside their immediate expertise.) The second factor, which supports the first, is a culture of knowledge reuse. By maintaining a rich repository of expertise over time, they are able to support their generalized knowledge, reduce response time, promote consistency, and ultimately provide a high level of service for the airlines.

The GTS-West team consists of over 200 engineers and administrators divided among core aircraft service areas (Structures and Payloads, Avionics and Electrical, Hydraulic and Mechanical, Propulsion and Environmental), analytic support for these areas (Stress, Repair Design, Damage Tolerance Analysis, and Aging Aircraft Programs), and general customer service groups. Data collection has largely concentrated on Structures and Payloads and their primary analytic support team, Stress.

Structures and Payloads has the heaviest volume of service calls at GTS-West, more than double the nearest group. They are responsible for supporting all aspects of the airframe and all internal structural elements on both cargo and passenger aircraft. In 1999, they fielded approximately 12,000 actions and this number is climbing rapidly. (The increase has been 8-10% annually since 1993 and it is expected to be even higher now that the entire IAC fleet is post-production.)

Structure's primary support team is Stress. Stress provides all of the advanced stress analysis for the airworthiness of repair actions generated by the operators and approved by Structures. Typical results of stress analyses involve maximum load tolerances, expected lifetime of repairs, safety characteristics of repairs and materials performance. They also initiate the FAA approval process, via designated engineering representatives, for these repairs.

[2] This group is classic example of a High-Reliability Organization (HRO). These are organizations with zero tolerance for error, where even the slightest mistake can have catastrophic consequences. Two common examples of HRO's are nuclear power plant control rooms and aircraft carrier flight decks [14]. As a result of their high-stakes operations, HRO's tend to have multiple layers of redundancy designed into their procedures.

STUDY DETAILS

The primary data collected come from thirteen months of participant observation at GTS-West. This study included extensive observation and interviewing of the engineering teams, mapping information flows, capture of critical incidents, systematic tracking of document lifecycles, and participation in a 25-week business process re-engineering effort. This has also been augmented with visits to other GTS offices, interviews at a major airline repair facility, and the evaluation of considerable secondary material.

Distributed cognition [7] and grounded theory [13] provide the framework for the preliminary analysis of these data. Boundary objects [12,9], a fundamental theoretical construct in this analysis, are further defined below.

WORK OVERVIEW

Requests from the airlines come in through an augmented e-mail system which is routed to a service engineering supervisor. The supervisor routes a query or problem to an appropriate service engineer based on its content and their work load. The engineer will then contact any number of the analytic support teams necessary to resolve the problem.

The vast majority of technical problems arising in the routine operation of an airline fleet are resolved locally by the operator's maintenance crews using the structural repair manuals provided by the manufacturer. (These are roughly analogous to FAQs.) Only exceptional problems, or problems requiring special certification, are routed to GTS.

In order to complete each service request, Structures and Stress rely not only upon each other, but upon a vast, complex web of information resources. This web often includes local experts, specialists throughout the company, blueprints, design specifications, regulatory guidelines, technical journals, records of operator communications, myriad databases, and a division-wide workflow management system (GlobalCOM). In addition, for every action requiring stress analysis both groups reference a primary element of GTS-West's organizational memory, a legacy STAIRS database [3,4] of "Records of Conversation" (ROCs) - summaries of all prior operator requests, stress analyses, final answers and FAA approvals.

In general, the solutions they generate must be prompt; this is a competitive customer support industry. They must be complete, precise and error-free; these are high-reliability, high-liability situations. They must be thoroughly documented; these are tightly regulated activities.

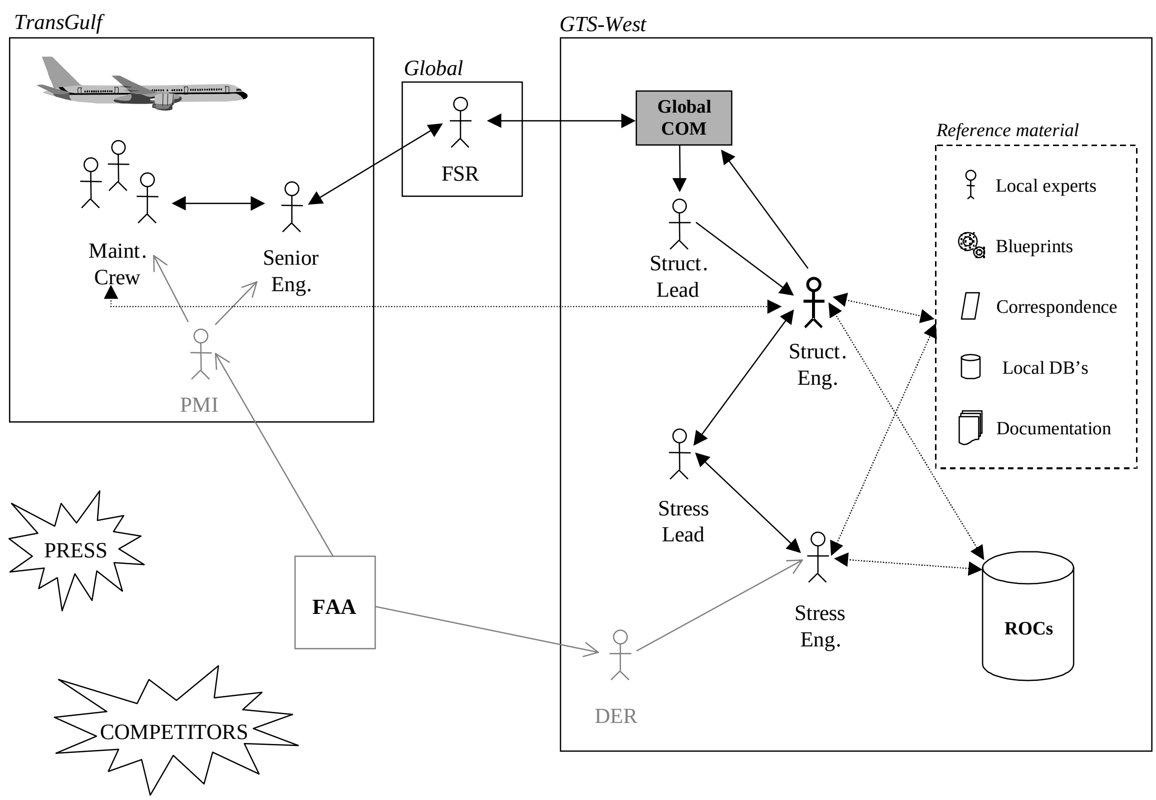

Figure 1: Abstracted information flows in the AOG scenario.

BOUNDARY OBJECTS

A useful notion in this analysis of routine reuse at GTS-West is that of boundary objects, which are defined as,

> "objects which both inhabit several intersecting social worlds and satisfy the information requirements of each of them… objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites."([12], p. 393)

The primary analytical powers boundary objects afford are an ability to represent multiple perspectives of a single information artifact, interpret the negotiations which govern its creation and evolution, and map the intersection of social worlds onto aspects of the artifact itself.

Revisiting the opening AOG scenario, expanded and diagrammed in figure 1, one notes that the information flows at GTS-West are rife with information artifacts such as these. Some artifacts which are prime candidates for consideration as boundary objects are the originating GlobalCOM request, the ROC required for stress analysis, the historical ROC which saved the day, the structural repair manuals, the blueprints and the technical journals. Extensive negotiation, across both group and organizational boundaries, surrounded each of these artifacts.

Given our expressed interested in better understanding the behavior of reuse, we have focused our attention on the ROCs. We are especially interested in their evolution over time, attending to their transformations at key organizational boundaries and cycles of decontextualization and recontextualization. To highlight some of the routine complexities in this process, we turn again to another scenario (after a brief introduction to prioritization classes).

PRIORITIZATION CLASSES

Job prioritization is the primary stressor of the information flows at GTS-West. They have three standard classes of prioritization, each with its own set of constraints. The most pressing is the AOG, as typified in the opening scenario. Dealing with aircraft in revenue operation, these require same-day resolution. The second class covers a range of priority situations which require next-day turnaround. These requests most often involve work stoppage crises at repair stations. The final class provides for the industry standard 3-5 business day response time. A brief scenario introducing this final class follows.

SCENARIO (Gears)

A request has come in to GlobalCOM from an independent repair facility in Singapore. During routine maintenance of a forward landing gear assembly,[3] their mechanics have discovered corrosion in the housing at the attachments for the steering cylinders. They are suggesting manufacturing custom bushings to accommodate the corrosion. Would this repair be approved by Global Airframe? If so, what alloy would Global recommend? This written request is accompanied by supporting documentation: two copies of pages from the IAC overhaul manual which show the parts and their allowable tolerances (these are annotated with measurements specific to this job) and a sketch of the housing placing the discrepant measurements in context.

The service engineer, who was assigned this job by his supervisor via GlobalCOM, creates a ROC to request analysis from Stress. In the process, he augments the original request with additional data he deems relevant from the accompanying annotated IAC pages and sketch. (Most notably he foregrounds the details of prior work done on this sub-assembly to combat corrosion (one of the bores has a spotface and a local blend out).)

As is often the case, the ROC is missing a measurement critical to a stress calculation. Since the analyst is barred from interacting with the airline, she has the service engineer request the missing figure.

The engineer calls the repair facility and leaves a voice-mail message. Due to the time zone differential, he knows he will not receive a reply today. The next morning though, he finds a reply by fax from a supervisor in Singapore. The measurement is more general than expected, but he runs it over to Stress regardless. He then requests a more specific number from Singapore by e-mail and is surprised to receive a phone call moments later – one of the repair crew was working overtime that night. He forwards this as well.

The highlighted historical repair information and retrieved measurement are of great assistance to the stress analyst. She is immediately able to see that any further work will bring these parts beyond operating tolerances. She documents her rationale in the ROC, including pointers to the reference materials that she used, and closes it out with the following assessment: "Subject part is not acceptable for ultimate strength. Due to the excessive rework on the steering cylinder attach bores, the margin of safety is negative. Remove from service." With the closed ROC in hand, the service engineer now tailors a well argued, legally binding reply to the repair station, breaking the bad news.

DECONTEXTAULIZATION / RECONTEXTUALIZATION

Decontextualization, is a process present in all biological and organizational memory systems. (You simply cannot capture everything; you must reduce.) When information artifacts are archived for future use, details are omitted and

[3] Gear assemblies are designed to be interchangeable, so that maintenance of a swapped out unit does not require downtime for the entire aircraft.

much context is lost. Sometimes this is intentional, e.g. streamlining for efficiency or legal liability, other times it is incidental.

The archival process for the Singapore gear assembly ROC was no different. The electronic archive contained none of the measurement clarifications. The physical archive contained the fax, but not the telephone update.

Years later when this ROC is referenced for a similar repair (as was the case in the first Scenario), of the three potential measurements, the engineer will only have the opportunity to find at most two of the disputed measurements, neither of which is the most correct. He will also have impoverished contextual cues to aid him in interpreting the relevance of the two and pointing him to the missing third.

It is in this process of recontextualization where IT and process improvements can be most helpful. There are many possibilities, from mining correspondence archives, to providing pointers into the expertise network in the department, to embedding links to relevant resources (e.g. personal technical journals). As the analysis of this study deepens, these ideas will mature and more robust requirements will emerge.

CONCLUSION

This field study at GTS-West holds considerable promise for better understanding how boundary objects mediate knowledge reuse activity and support the maintenance and use of organizational memories. This deep understanding of natural behavior can be leveraged to critically inform the usability requirements analysis for the design of information technologies to best support these endeavors.

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