Beyond Boundary Objects: Collaborative Reuse in Aircraft Technical Support

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ABSTRACT
Boundary objects are a critical, but understudied, theoretical construct in CSCW. Through a field study of aircraft technical support, we examined the role of boundary objects in the practical achievement of safety by service engineers. Their resolution of repair requests was preserved in the organization's memory via three compound boundary objects. These crystallizations did not manifest a static interpretation, but instead were continually re-interpreted in light of meta-negotiations. This suggests design implications for organizational memory systems which can more fluidly represent the meta-negotiations surrounding boundary objects.

KEYWORDS
Boundary objects, collaborative work, high reliability organizations, information reuse, organizational memory, safety, service engineering, hotlines, technical support.

1. INTRODUCTION

The CSCW literature has extensively used Star's boundary objects (1989), shared informational objects that can be used by different groups for their own purposes. For example, work has found boundary objects to be critical components of common information spaces (Bannon and Bødker, 1997; Schmidt and Bannon, 1992) and organizational memory (Ackerman and Halverson, 2004). Examples of boundary objects include:

> Blueprints. Design engineers craft these production drawings for use in manufacturing, however, they become used by "marketing, sales, inventory control, and accounting" (Henderson, 1999, p. 86).
>
> Employee payroll records in a database. A personnel department, responsible for the records, fully understands any employment issues for each employee. Yet others can use those records to identify employment status without knowing any of the details (Ackerman and Halverson, 2004).

Indeed, we have found boundary objects theoretically useful in our descriptions of technical help and information reuse. However, despite boundary objects' theoretical importance in collaborative work, relatively more work is required to understand boundary objects in practice. For example, understanding how to augment memory artifacts or technical support, especially as these are often situated activities, requires a deeper understanding of boundary objects as actually used.

This research project began as an empirical examination of information reuse in a field setting, in order to further the design of organizational memory systems. We were especially interested in providing greater flexibility for both anticipated and unanticipated reuse and thus explored information types that should supplement current records. Based on the literature, we anticipated that boundary objects would be particularly useful in facilitating our understanding and would hold the greatest potential for augmentation. To determine this, we rooted the analysis of the data within the conceptual framework of boundary objects.

The study took place in a technical support center, which we call GTS-West. GTS-West is a high-reliability, safety-critical organization: It supports maintenance engineers dealing with passenger airplanes. For example, if a baggage handler slams the conveyor against a plane while loading suitcases, GTS-West takes the call to help evaluate the damage. GTS-West also handles a wide variety of service requests, determining whether suggested repairs or modifications will be adequate.

Such an environment facilitates the examination of boundary objects. Numerous repair requests run through GTS-West everyday; every one is unique though within recognizable patterns. All aircraft are idiosyncratic, not only are they each subtly different rolling off the assembly line due to manufacturing variances, but they encounter very different operating conditions during their life span. Thus, responses to routine aging (e.g., corrosion, metal fatigue) and natural events (e.g., lightning strikes, hail damage) must be customized to each individual unit given its history and current operating environment. The repair processes may be standardized (e.g., blend out and doubler mounting for corrosion damage), but their applications are unique. As well, diverse groups actively collaborate in finding solutions, crossing many inter- and intra-organizational boundaries in the process. Most importantly, because GTS-West is a safety-critical organization, the creation and use of information artifacts are more controlled, providing an easier examination of their use.

During the analysis process we came to realize that the current conceptualization of boundary objects was insufficient to describe the phenomena we observed. In short, what we found is that the current discussion of boundary objects must be expanded in order to make sense of our fieldwork findings (in the spirit of Schmidt and Bannon (1992), Ackerman and Halverson (2004), and Lee (2005)). As will be shown, we found certain process and meta-negotiation information to be critical to the use of the boundary objects in the field site. These boundary objects are wrapped up in other institutional processes and negotiations, and an understanding of this is often critical to both their production and use. In this manner, this study extends the examination of boundary objects to include surrounding artifacts and processes, as Lee and others argue CSCW should.

The paper proceeds as follows: After a brief literature review focused on boundary objects in CSCW, we will present the site, the primary groups, and their organizational routines and information flows, both official and informal. The paper then proceeds to present two service requests. The first, a relatively simple case, reveals the basic use of boundary objects in this environment. The second uncovers some of the exceptional and situated handling of the boundary objects. The paper concludes with some theoretical extensions to boundary objects and design implications.

2. LITERATURE REVIEW

2.1 BOUNDARY OBJECTS

The concept of boundary objects was originally presented within the artificial intelligence research community to better understand distributed decision making (Star, 1989). It was adapted to explain work environments by Star and Griesemer (1989) in their historical study of heterogeneous scientific work at Berkeley's Museum of Vertebrate Zoology. In their canonical definition, they present boundary objects as being:

> …objects which both inhabit several intersecting social worlds and satisfy the informational requirements of each of them. Boundary objects are objects which are 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. They are weakly structured in common use, and become strongly structured in individual use. These objects may be abstract or concrete. They have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation. The creation and management of boundary objects is a key process in developing and maintaining coherence across intersecting social worlds. (p. 393)

Boundary objects then, in their myriad forms, are bridges between different communities of practice (Wenger, 1998) or even social worlds (Becker, 1982). Via their plasticity of meaning they translate ideas, viewpoints, and values across otherwise difficult to traverse organizational boundaries.

2.2 AS USED IN CSCW RESEARCH

Since the introduction of the boundary object concept[1], research has matured in several different directions. Bowker and Star (1999) have focused on the role of boundary objects in translation, specifically how boundary objects assist in classification and how they calcify into standards. Other studies have focused on how boundary objects play in the micro-negotiations within developing shared understanding. Henderson's (1998) work with design engineers centered on how engineers use diagrams, drawings, and blueprints as points of negotiation. She focused specifically on the changes, both positive and negative, occurring as the CAD revolution shifted these artifacts from paper to digital form. Bechky (2003) also attended to the role that drawings play in negotiations among engineers. However, she focused on drawings that explicitly span social world boundaries (e.g., moving from design to manufacturing). Kim and King (2000) extended this work to include the engineering problem itself as a boundary object. Their engineers came together to discuss broken foundry machinery. As well, the concept is being applied to some software engineering problems. Recent studies have addressed information mechanisms used by dispersed volunteer open-source programmers (Yamauchi, et al., 2000) and the evolution of proto-architectures and project plans at NASA (Bergman, Mark, and Lyytinen, 2004). The Software Engineering Institute and the Association for Computing Machinery have hosted workshops on the concept's relation to information flow, modeling, and interface design (Lutters and Seaman, 2004).

More to the point of this paper, other researchers have examined what is inscribed on the boundary objects in the processes of negotiation, and the meanings behind those inscriptions. Berg and Bowker (1997) detail how patient records in hospitals act as boundary objects "producing" the patient for physicians, technicians, and nursing staff via the mappings between the individual and their surrogate representation in the record. Bossen's work on other health care documents (2002) has examined their role as mediators between the different social worlds of surgeons, physicians, technicians, nurses and administrators. Mambrey and Robinson (1997), in the GMD's POLITeam project, looked at boundary objects and their inscriptions, primarily those of workflow. In their study of a German ministry, inscriptions detailing workflow allowed groups to understand the relative meanings for an artifact. They also noted that boundary objects could be compound: Folders circulated with enclosed papers and documents. Other key studies examining the coordination of work across time involved shift changes at a paper mill (Kovalainen, Robinson, and Auramaki, 1998) and sharing of environmental planning data sets (Van House, Butler, and Schiff, 1998). Ackerman and Halverson (2004) reported on a personnel hotline, detailing the information flows within telephone calls and the construction of the answers. In all of these, as Star points out, boundary objects were necessarily decontextualized on one side of the boundary, and reconstructed on the other. The reconstruction of the boundary object, for example a personnel record, was found to be critical to reusing information in organizations.

2.3 CHALLENGES

Perhaps due to the tool development focus in CSCW, computationally facile characteristics of boundary objects have been promoted to the foreground in the literature. Star's original definition includes such diverse notions of boundary objects as coincident boundaries (e.g., the shared understanding of the geopolitical boundary of the state of California) and ideal types. CSCW has focused on the more tractable information processing objects such as standardized forms and repositories. In doing so, there has been an overemphasis on boundary objects as physical artifacts. This limits the analytical power that boundary objects bring to understanding negotiation and mediation in routine work.

Other researchers have noted this shortcoming in the concept's usefulness in understanding collaborative work. Schmidt and Simone (1996) presented an alternative view of coordination mechanisms, more explicitly foregrounding the negotiation process and de-emphasizing the artifactness. More recently, Lee (2005) suggested classes of more free-form boundary negotiating artifacts, less structured and standardized than boundary objects.

In this paper we seek to continue this examination of the applicability of boundary objects to understanding the complexities of collaborative work. Through the unpacking of two routine work cases and related critical incidents we will specifically explore the tension between boundary objects as artifacts and as processes. We will foreground their temporal properties, seeking to understand both the archival process and the object's place within the mesh of ongoing event streams.

3. SITE SELECTION AND DATA COLLECTION

Customer support is a rich venue for exploring the use of organizational information in general (Ackerman and Halverson, 2004). Hotline 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

As mentioned, this paper reports on a field study of Global Technical Support (GTS), the division within Global Airframe, an international commercial aircraft manufacturer, that provides technical support for all operators of Global aircraft (e.g., airlines and airfreight companies). Technical support in this domain involves assisting in creating, validating, and authorizing one-of-a-kind maintenance repairs to individual aircraft in an airline's fleet. For example, if a commercial jet received lightning damage while en route to a foreign destination, GTS-West would create and approve a temporary repair allowing them to safely return to their home maintenance facility where they could replace the damaged section according to standard procedure. This type of support is required of all airframe manufacturers by the United States' Federal Aviation Administration (FAA), but technical support has also been a key selling point for Global Airframe in an increasingly competitive global market.

GTS offices are located throughout the United States; the study focused on one in particular, GTS-West. This office 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 three thousand in-service aircraft, all of which are post-production, having been manufactured by a merger-partner.

In many ways GTS-West is a typical technical support environment; however, it exhibits some uniquely defining characteristics. As mentioned, it has a high requirement for reliability and safety, but with growing requirements for turnaround time and price. Furthermore, this situation exists within a complex regulatory and legal liability web, which must be addressed by all information processes. Finally, there is a constant concern about the public visibility of mistakes.

The analysis of GTS-West here is based upon thirteen months of participation observation at the site by the first author (Lutters, 2001). The findings discussed in this paper emerged from a detailed analysis of twenty cases of airline support requests followed throughout the organization. Because of access restrictions, additional complete cases could not be obtained, nor could audio- or video-taping occur. These cases, therefore, were supplemented with over 210 critical incident descriptions (i.e., parts of cases) captured in field notes, as well as over 80 detailed interviews with service personnel, similarly captured. The first author also had extensive access to archival and secondary materials (including critical information artifacts) and participated in twenty-five weeks of business process re-engineering meetings. The cases, critical incidents, and interviews were coded and analyzed according to standard qualitative techniques (Strauss and Corbin, 1998).

All identifiers, including the site and people, have been made anonymous. Any quotations are from the field notes.

4. GTS-WEST

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. (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 information reuse.

The GTS-West team consists of over 200 engineers and administrators divided among core aircraft service areas (e.g., Structures, Payloads, Hydraulics), analytic support for these areas (e.g., Stress, Repair Design, Damage Tolerance Analysis), and general customer service groups. Aircraft are exceedingly complex pieces of machinery, with many interdependent systems. Thus, it is the exception, rather than the rule, that a service request can be resolved without collaboration between at least two of these groups. This study concentrated primarily on the relationship between the Structures group and their primary analytic support group, Stress.

Structures is a group of 27 service engineers, responsible for supporting all aspects of the airframe on both cargo and passenger aircraft. They are subdivided into three teams by aircraft type (long-haul, short-haul, and heritage aircraft). These teams are managed as a single group, with a joint manager, but in day-to-day operations they operate quite independently under their own supervisors. Structures had the heaviest volume of service calls at GTS-West, more than double the nearest group. In 1999, they fielded approximately 12,000 actions and this number was climbing rapidly. (The increase has been 8-10% annually since 1993. It is expected to be even higher now that its entire fleet is post-production.)

Structure's primary support team is Stress. Stress provides all of the advanced stress analysis for the air-worthiness of repair actions generated by the operators and approved by Structures. These analyses are mathematical models of varying complexity which determine the impact the repair will have on the sustainable strength of the assembly and assist in predicting the repair's longevity. Typical results of these models involve maximum load tolerances, expected lifetime of repairs, safety characteristics of repairs, and materials performance. Stress also initiates and coordinates the FAA approval process for these repairs. Structures works closely with Stress for over 80% of their actions; the job simply could not be done without this collaboration.

Organizationally, Stress is equivalent in size with 32 engineers. Stress has a single manager, but is subdivided into four teams, each with its own supervisor. Three teams are arranged to mirror Structure's subdivisions (short-haul, long-haul and heritage aircraft) and one exclusively serves the special analysis needs of the hydraulic group. The emphasis in the study was on the first three teams, those that interacted directly with Structures.

As with all the other GTS facilities, the GTS-West office is located onsite at the production facility. This location decision is deliberate, providing the service engineers with easy access to all of Global's expertise for their airplanes, from original designers, to sales staff, to technical writers, to the team that rivets the nose cone fasteners. This proximity also allows GTS-West to draw its staffing heavily from those who have worked on particular aircraft models elsewhere in the organization (e.g., design, manufacturing).

Their actual office is a vast, open floor plan with a combination of open desks and low (3') cubicle dividers. Stress is physically sandwiched between their two primary service engineering teams, Structures and Hydraulics, facilitating frequent face-to-face interaction. For the majority of the study, the first author sat at the physical boundary between Stress and Structures, near the supervisors for Stress.

In order to understand routine interactions in this environment, it is critical to understand the groups more fully. The following sections detail the core differences between the groups, as well as their functions.

4.1 STRUCTURES AND STRESS

The engineers in Structures and Stress belong to different communities of practice (Wenger, 1998) – they have different professional backgrounds, working cultures, and vocabularies. Culturally, the Structures group resembles customer service organizations, with its attention to timeliness, while Stress is more akin to a quality assurance team. While relations between the groups are usually cordial, the tensions sparked by these often opposing worldviews are frequently palpable. It was not uncommon for Structures engineers to toss a request packet onto a Stress desk and demand immediate attention for their job. One particularly difficult month seeded the departure of both groups' line-managers and provided the genesis for the business process reengineering effort to address their collaborative processes. In order to better interpret the interactions surrounding a service request resolution, some of the groups' core differences will be addressed next.

4.1.1 The Structures Group

As service engineers, the people in Structures are the interface with the airline's maintenance engineers. They directly handle all structural support queries from the airlines. In this capacity their experience is quite similar to other second-tier technical support environments. The days are long, grueling, and high-stress. The stream of incoming requests is unrelenting. Praise for a job well done is rare, while operator complaints are the norm.

Service engineers are prepared for this work environment though prior aircraft maintenance experience. No one starts their career in GTS-West, all engineers have worked elsewhere within Global or with one of the operators. (Staff raids between the two are common. Work experience at the manufacturer provides design insights not available elsewhere, while time with the operators provides hands-on field experience from the customer's perspective. A common perception is that the strongest engineers have both.) Service engineering tends to be a career destination for engineers, as it affords no clear promotion strategy out of the group.

A typical day for a Structures engineer begins with reviewing their outstanding jobs from the day before and prioritizing new job assignments routed to them via the workflow management system and approved by their supervisor. (While they work a typical business day/week, the operators they support operate globally twenty four hours a day, seven days a week. New jobs arrive continuously.) An engineer may start a day with one to three jobs depending on the seniority of the engineer and the complexity of the task. While the engineer's desire is to process these jobs serially, their dependence on the services of analytic units, requests for more information from the operator, and approvals from the FAA necessitates multi-tasking. Additional jobs will be added throughout the day as their schedule clears or the incoming assignments back up. They find satisfaction in clearing as many jobs as possible before the end of the day. (This is akin to hospital staff "clearing the board" of patients in an emergency room.) Someone on the team is always on call, twenty-four hours a day, seven days a week, for emergency processing of critical jobs.

The service engineers know their customers well and are quite savvy at tailoring information to match the operator’s needs and abilities. Many of these service engineers have worked their way up through the field support or manufacturing segments of Global Airframe and are accustomed to being close to both the customer and product. They tend to be gregarious, extroverted, and cynically humorous.

Because of a customer-centered business model, Structures breeds a culture of efficiency and expediency. Via the tools described below, everything is monitored and measured by management: timeliness, completeness of response, and customer satisfaction. These metrics are directly tied to each individual’s performance rating, salary increases, and bonuses.

These engineers have the final say on all repair recommendations and are ultimately held individually responsible for them. They are meant to be the sole contact the operator has with GTS-West, black-boxing all other functions.

4.1.2 The Stress Group

The Stress analyst’s job consists largely of gathering information to build an evidentiary case for a particular repair decision and then running through the requisite mathematical models to test that case. The analysts stand in ultimate judgment on each repair – either it is safe or it is not, period.

By deliberate organizational design, Stress engineers do not have contact with the operators. This objective detachment is one critical component of the system of checks and balances that yields the high-reliability of response required by aircraft repair. Not having to please the customer allows Stress to be more impartial in their assessments. However, this detachment is a perpetual source of friction between the two groups, as Stress often has to work in a contextual vacuum, solely dependent upon the Structures engineer for the relevant details surrounding the current job.

The Stress team consists of “engineers’ engineers” – more abstract and theoretical than the service engineers, some even hold doctorate degrees. In recent years, intense downsizing of the design and production units at this plant has enabled some of the best analysts from these groups to join Stress. As with Structures, this tends to be a career destination.

The organization’s emphasis on safety has fostered within Stress a culture obsessed with reliability. Stress engineers will proudly tell you that their calculations determine whether a plane flies or not. Nearly all will work on a problem until they are convinced beyond reasonable doubt that the repair is suitable for strength. This passion for error-free evaluations comes at the cost of timeliness (sometimes the calculations for particularly onerous problems can stretch over days), which clearly puts them at odds with Structure’s response-time focused service engineers. It is in this tension of tight conflict and collaboration that all routine work is accomplished.

The following section provides a high-level overview of the routine collaborative work between Structures and Stress.

5.0 ORGANIZATIONAL ROUTINES

As with Mambrey and Robinson’s (1997) ministry speech routing, the official processes of work are highly organizational, regulated and public – in short, Weberian bureaucratic. Unofficially, the work is characterized by informal arrangements and private flexibility. Yet, the work is highly reliable, a reliability gained by the organizational processes and often enough through individual initiative to safeguard and even rescue the organizational routines to be described below.

The vast majority of technical problems arising in the usual operation of an airline fleet are resolved locally by the operator’s maintenance crews using the structural repair manuals provided by the manufacturer. For anything standard, maintenance engineers can look up solutions in the Service Request Manuals (SRMs), roughly analogous to FAQs for maintenance questions. Only exceptional problems, or problems requiring special certification, are routed to GTS.

These operator requests arrive via an e-mail system augmented to function as a workflow management tool, GlobalCOM, which routes them to service engineering supervisors based on the aircraft type or section in question. Each supervisor assigns the request to an appropriate service engineer based on its content and their workload. The engineer will then contact any number of the analytic support teams necessary to resolve the problem.

In order to complete each service request, Structures and Stress rely not only upon each other, but also 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. In addition, for every action requiring stress analysis both groups use a legacy STAIRS database of “Records of Conversations” (ROCs) – summaries of all prior operator requests, stress analyses, final answers, and FAA approvals. The simple distinction between these two systems is that GlobalCOM manages all external coordination while the ROC coordinates all internal collaboration. Every repair request is a unique boundary object instance in each system, with crisp boundaries between GTS-West and the operator, and among Structures, Stress, the FAA, and the other analytic support teams.

These two archival databases are a part of a rich information environment at GTS-West. Everything in this organization has a history – detailed aircraft “books” describe the life events for each craft, every service engineer has a storied reputation from their years of experience, every process displays labyrinthine change histories reflecting the complex relationships with regulatory agencies, and even individual parts have histories. (Many a job has been saved by serendipitous searches of the serial numbers minutely etched on each piece). For an organizational culture so steeped in history, there is little time to maintain it. The jobs come quickly, often in crisis, and demand rapid resolution.

For Structures and Stress there are three standard classes of prioritization. The most pressing is “aircraft on ground” (AOG) which deals with aircraft in revenue operation and requires a same-day resolution. The second class, “urgent,” covers a range of situations that require next-day turnaround. These most often involve work stoppage crises at repair stations. The final class provides for the industry standard 3-5 business day response times. A rough distribution of these jobs in 2000 was 30% AOG, 55% urgent, and 15% regular. (This distribution was quite different for the other groups at GTS-West, as Structures routinely received the highest percentage of both AOG and urgent jobs.) The first case below is an AOG request; the second is an urgent.

This section introduced, in general, the primary flows and the information systems which support them. The following case, among the simplest in the field notes, will embody these processes by following a service engineer and a stress analysis through a typical Monday morning job.

5.1 CASE 1: BASIC INFORMATION PROCESSES

This case highlights the officially sanctioned and unofficial organizational processes applied to understand and solve the problem. (A simplified mapping of the core information flows is provided in figure 1.) As discussed above, the vast majority of services calls to GTS-West involve unanticipated deviances discovered during routine aircraft inspections. These are most often caused by environmental factors – scratches from collisions with ground equipment, dents from hail, routine metal fatigue and corrosion. In these situations the aircraft are out of service and are in a routine maintenance location (e.g., operator's hub airport). However, about 30% of incoming jobs are AOG's where the aircraft is in active service or not in a location convenient for repair. This first case is an AOG where the aircraft is still in its scheduled flight rotation, but its problem was discovered while at one of the operator's main facilities.

In this case, Beechwood International Jet experienced damage to the auxiliary power unit (APU)[2] cover ("door") on one of their short-haul N-27 jets upon landing. Beechwood did not have the replacement part in stock, nor did any of their vendors. The earliest they could have the part delivered was two weeks - extremely expensive downtime for their jet, especially for an important but non-critical component such as the APU. In their search, however, they did find a replacement door to an N-23, part of the same N-20 model family as the N-27. They needed to contact the manufacturer to verify if this replacement would be acceptable for a ten-day temporary repair.

Figure 1: A simplification of the information flows in Case 1.

It was early Monday morning when this high priority, "airplane on ground" call from Beechwood was routed to Todd, a senior structures engineer, by his supervisor. Todd was sifting through the seventy e-mail messages that had backed up in his inbox from the last couple of hectic AOG-filled days, trying to prioritize them into a reasonable schedule for the day. With this new AOG interruption, he abandoned his effort and got to work right away, remarking “in today, due today!”

After a quick review of Beechwood’s request, Todd concluded that this proposal was a reasonable course of action, but that it would require both a Stress analysis and a Systems consultation before final approval. (Systems is another analytic support group responsible for propulsion and environmental components.) “We have to see if the door fits. Systems has to see if it works.” He edited Beechwood’s request to create an initial ROC, which he then submitted to Stress.

Kai was assigned as the Stress analyst for this job. His task was to confirm that “this [door] fits as the other would fit. [To do this] the door has to fit perfectly – hinge, latch, everything.”

5.1.1 Workarounds

To step back, the beginning of the case has unfolded in line with the official process. Things now begin to go awry, and to accomplish the everyday activity of the organization, the official processes of the organization must be supplemented and transformed by a set of informal working arrangements (Suchman, 1983). Kai facilely deviates from the official process in favor of quick solutions to potentially time consuming problems to best service this AOG. He will personally research details overlooked by Todd (instead of returning the request to him). When he discovers that a requisite blueprint is missing, he will run to the library and generate a new one (instead of placing an order for a reprint). He will walk the job over to the Systems department for a needed consultation (instead of reassigning the ROC).

Kai started the job by pulling the relevant blueprints, “I’m not one hundred percent familiar with this door.” He believed that the two doors look the same but he needed to verify that they had the same material properties. Kai needed to find the supplemental blueprints which specifically described the N-23 and N-27 doors. One of the blueprints was missing from the filing cabinet. He asked around but could not locate it. Instead of ordering a new one, he ran off to the library to generate a new blueprint. With this he discovered that the N-27 door had an air intake hole, not present on the N-23, as well as a different structure on the backside of the door.

Kai acknowledged that this was now outside of his expertise, “well, it looks like the N-27 has a different APU. Different style, model, supplier… something. This requires more room for an input fan. It sits on top. The others don’t have one like that.” He would ask a service engineer in the Systems department to examine the assembly behind the door, to make sure that the N-23 door will not damage the APU itself – “to make sure there are not problems and just generally get their okay.”

With most routine jobs this would be reassigned to the Systems engineer. But given the AOG priority, Kai commented, “I’ll just walk down the hall and list him as a reference. I don’t know his name, but I know where he sits. I walked by his desk earlier and he wasn’t in. I was just going to write him a note to put on his chair.”

Bud, the Systems engineer, returned his evaluation. He had concluded that the door would not interfere with the APU mechanics, but it would render the unit unsafe to operate. In addition to seeking this expertise from Systems, Kai also consulted the Minimum Operating Equipment List (MOEL), a document that lists what subsystems are required to be in operating condition for any given aircraft model. “If it’s not on that list, I’m not approving it [as operational]. No way.”

The APU was not on the list, so the repair instructions back to Beechwood would allow the use of the N-23 door but require that the APU be tagged “in-op” (not operational). “Since it will be in-op they’ll tag it in the cockpit. Put a red tag or tape on it [the physical control switch], and record it in the flight log. That’s all their problem, not ours.”

Kai’s work was then checked by his supervisor. The role of supervisors, both within Stress and Structures, is critical. Kai was confident that his supervisor’s final check of his response would highlight and repair any irregularities.

After the check, Kai approved the use of the N-23 door. He submitted the results of his analysis to Todd in the ROC. In the ROC, however, he also requested that Todd walk through the repair with the Beechwood crew, to make them aware of the differences in the doors. In the ideal blueprint world, the door would be a perfect fit. In the real world the aged fuselage could be slightly worn or warped from years of use. In addition the door might not be new stock, but might be a used part, worn and warped itself from years of use. “They’re [Beechwood] usually pretty good, but there could be a gap this big (holds up index finger and thumb to indicate about an inch).” To prevent this Kai was explicit about the measurements for all of the contact surfaces. “If these measurements were all met, there is no way the door can be a misfit.”

Throughout this Kai was critically aware of the time pressure, “Oh, I know this is an AOG. I should have it done in an hour or so. I know they [Beechwood] are waiting for this. It’s on the ground.” He worked through lunch to finish the job and hand it off to Todd. When he finally was able to take a mid-afternoon lunch break, his chair became buried in “respond to me now” notes. The job was resolved in a matter of hours. “Once we saw that there was no problem with fit, we let it go at that. It is only for ten days, temporary. I sent it off to Todd, oh, about 12:45 or 1:00.” Todd then edited Kai’s response and sent it to Beechwood by 2:15pm. “We let them go ahead and do it.”

The case has been resolved. The next two sections highlight how safety is achieved, both officially and unofficially, including how the unofficial is officially recognized.

5.1.2 Achieving Safety

What is most important to Todd and Kai is safety within the efficiency requirements of the situation. For them, this is “achieving timeliness.” It is not considered “cutting corners,” which to the participants implies jeopardizing safety. Achieving timeliness and safety simultaneously occurs through the support of official organizational structures as well as the informal workarounds that achieve outcomes suitable for the official process.

We have already highlighted many of the organizational structures that promote safety and guide the informal work. There were several official processes described above. As well, this entire story was surrounded by the regulatory oversight of the United States government’s FAA, which monitors all domestic aircraft maintenance and operation. The internal, operating processes at GTS-West are all regulated by the FAA and are open to audit by the agency at any time.

The FAA appeared at several points in this case. The MOEL document, which lists the equipment necessary to fly a plane, is an agreement between Global and FAA, required for the original airline certification for the N-27 by the FAA. More to the point, Beechwood requested an FAA certificate, the 8110. An 8110 signifies that a repair has been done in accordance with all FAA regulations, and is required for all major repairs completed by US operators. Non-US operators typically use the 8110 in lieu of their own countries' certification, because FAA rules meet or exceed those of all other countries. Regardless, a complete history of 8110s must be supplied for all repairs to aircraft sold to US operators.

Within the standard process, after the ROC has been approved by the Stress supervisor, a request for an 8110 is made and is approved by another level of double checking, the designated engineering representative (DER). The DER is a GTS-West employee who has been selected, trained by, and jointly reports to the FAA. They are considered by their colleagues and by themselves to be the most experienced and expert of the GTS-West engineers. While DER's are responsible for validating the repair designs, their counterparts in the field, the principal maintenance inspectors (PMIs), inspect the actual implementation of those repairs. They ensure that the repairs are carried out by the operators according to the guidelines provided by GTS-West and approved by the DER.

In the above case, Beechwood optimistically requested an 8110 on the off-chance that the N-23 door replacement could be permanent. Because the repair was found suitable only for 10 days, this repair was not submitted to the DER. Given the short life time of this repair, Beechwood should order the permanent APU door immediately. While Kai is skeptical that they will, he cannot pressure them to do so – "What do I win? Nothing. That's their responsibility. I can't care! Just give them a solid response and that's it. We just provide the answer, the rest is up to them." This highlights the severity of some of the organizational boundaries at play in this scenario.

In Weick and Roberts' (1993) terms, the DERs and PMIs provide an added level of redundancy to a High-Reliability Organization (HRO). HROs are organizations with zero tolerance for error, where even the slightest mistake can have catastrophic consequences. As a result, HROs have multiple layers of redundancy designed into their procedures. At first glance, the DER arrangement, with the DER being a GTS employee, may seem suspect as a level of redundancy. However, as with the labor inspectors in Bannon and Bødker (1997), this arrangement is the only one that could preserve the trade secrets of

Global Airframe. If the DERs were federal employees, the trade secrets would be subject to US Freedom of Information Act requests. A more important consideration, though, is that only someone internal to GTS, with an understanding of its planes, processes and people, could determine what is "achieving timeliness" and not "cutting-corners." Officially, this is recognition of how things really are made to work to accomplish safety.

In addition to the FAA, there is another critical layer of redundancy. Global maintains an international network of field service associates (FSAs). These individuals are housed at key operator locations – hub airports and major repair facilities. They are the front line in customer support. For GTS-West they frequently act as a filter, performing triage on requests and formatting requests to GTS-West standards.

At this Beechwood maintenance facility, Global has a FSA, Vincent, who facilitates service requests from Beechwood maintenance engineers to and from the GTS-West engineers. In this particular case since Kai knows and trusts Vincent he is flexible with the contact surface measurement requirements for the APU door installation. He is confident that Vincent as gatekeeper will ensure this is communicated and accomplished correctly.

In the interest of meeting the AOG efficiency requirements Kai pushes some of the onus for reliability outside of GTS-West and onto the operator. This does not concern him as he has a personal relationship with this FSA, trusts his sense of safety and knows he will do the right thing. He is also confident that he will manage the interactions with the PMI, relieving them of this added layer of complexity.

The organizational structures play only a part in accomplishing safety and timeliness simultaneously. We observed several workarounds above. For example, in handling a routine job, Kai should have reassigned the Beechwood ROC to the Systems department for consultation. The officially sanctioned process would have allowed the Systems supervisor to make an expert assignment of one of her engineers, and the results of this workflow element would have been automatically captured in the ROC. In the interest of time, Kai made the expertise judgment himself and inscribed the information on the ROC directly. His selection appeared to be appropriate, though the Systems engineer, Bud, did consult with one of his colleagues to confirm the response to Kai. As another workaround, Kai wrote Bud's name into the ROC as "a reference," a free-text list of resources consulted in building the evidentiary case for his recommendation. (However, Kai's supervisor edited the ROC to represent Bud as if the official workflow had been followed. Kai could not do this on his own.)

In general, people in both Stress and Structures are ultimately concerned with safety, making decisions that do not lead to incidents or accidents. However they approach this goal differently. For Stress, safety is primarily achieved through confidence in the strength modeling of the repair. They refer to this as the "quality of response." (This is reliability in the accountant's sense of consistency.) Structures, having more contextual understanding of the operator and the particulars of each unique repair request, achieves safety by finding feasible solutions that they know the operators can perform within their resource constraints. For them this is the "timeliness or fit of response." (Organizationally they are also rewarded for meeting request deadlines, which are set by the operators.) Safety is a practical accomplishment (Garfinkel, 1967) within GTS-West; the work results in safety and reliability only because the people work to make the results safe and reliable. This will be critical in seeing how the boundary objects are used in the next case.

5.1.3 Summary

To recap, the above was a relatively simple case. (Recall that all of GTS-West's service requests are in some way exceptional; completely routine repairs are handled internally by the airlines.) We presented this simple case to highlight the use of official processes with the flows of information across several boundaries and the use of informal working arrangements to actually accomplish the work.

This is consistent with Mambrey and Robinson's (1997) as well as others' findings. As in the German ministry, we also observed the use of compound artifacts in the accumulation within the ROC and GlobalCOM as well as the inscription of workflow onto the document. (Note however that the electronic nature of the workflow inscriptions make them amenable to being inside and outside of the document concurrently.)

In addition, we observed the creation of multiple boundary objects in coordination (and nearly simultaneously) and a tension between safety and timeliness which gets played out in the boundary object. We now move to a more complex case that more clearly elucidates the use of boundary objects within their context of use.

5.2 CASE 2: THE ROLE OF REUSE

The case began at SouthCentral Airline's regional maintenance facility. SouthCentral, like many large passenger operators, has large maintenance facilities at their hub airports where they perform routine fleet inspections and repairs on well-standardized schedules. Each facility has a sizeable maintenance crew and team of experienced repair engineers.

SouthCentral had one of their long haul aircraft in for scheduled maintenance. This time the aircraft was undergoing an extensive, month-long overhaul or "D-Check." (In a D-Check, they essentially disassemble and reassemble the plane.) As part of the check, the mechanics needed to verify compliance with a deadline for an FAA air-worthiness directive (AD). An AD is an FAA mandate to repair suspect or problematic parts; this is similar to an automobile recall. As part of the AD, the FAA tells operators how to inspect and repair the part. This AD was for the "dorsal fin attach angles" for the vertical stabilizer (i.e., where the leading edge of the tail assembly connects to the fuselage), a critical component.

Following a detailed inspection, SouthCentral realized that the current attach angle plate was not compliant with the AD and would need to be replaced. When the mechanics attempted to order the part, they discovered that the current plate was non-standard – it had eleven fasteners (i.e., rivets) in the body of the plane instead of the blueprint thirteen. These were arranged in a non-standard asymmetrical pattern. Having an incorrect number of fasteners in a non-standard configuration was a critical problem, as it was likely to impact the strength and stability of the plate. Furthermore, that the plate had only eleven fasteners meant that the replacement plate would need to be specially created to match, at very considerable expense. First though, they needed to determine whether the current eleven-fastener configuration would actually be compliant with the AD.

SouthCentral placed an urgent ("next day") request with GTS-West for assistance. The job came in to Structures, as in the above case, in the form of a GlobalCOM message with scanned sketches attached to the digitized body of the written request. Upon reviewing the job, the long-haul supervisor assigned the job to Nadya, a senior service engineer. (The case was observed from the time it was received by Nadya.) In a brief aside from the work, she explained that SouthCentral faced two possible resolutions: design a special replacement part to match the existing hole configuration or retool the fuselage "to blueprint" in order to accept the standard replacement part. The former, the option preferred by SouthCentral, would require analysis and special FAA approval for a minor deviation from the AD.

Nadya's first activity, as was often true with service requests, was to ensure that she understood the problem and had enough information to be able to build a reasonable case for a solution. SouthCentral had submitted some competent sketches of the attach angle plate along with their request, but they did not clarify the hole spacing. She wondered aloud about the location of the two missing fasteners, "Are they shaved off the end? Missing in the middle? Where?" She called SouthCentral and discovered that the holes were evenly spaced. Given her long experience with this model of aircraft, this was a much better than normal situation.

Nadya next thought through the fastener discrepancy. She explained: "You see, all aircraft are hand built, hand crafted. They are never exactly to blueprint. This was probably mis-drilled and they had to accommodate. Some supervisor inspected it and signed off. It was probably tagged… When engineering signs off on something they tag it." Aircraft manufacturing is at times more art than science, and minor design modifications are allowed on the shop floor to accommodate material variances, available expertise, and the like. Any such deviations from blueprint are "tagged" and signed off by a supervisor. A record is kept by the original operator. Checking the serial number for the SouthCentral craft, she commented, "It's 431, that's about thirty years old. It's pretty early in production. For something that old, it [the tag] is probably long gone. For a record like this, what's the chance of us still having it around? Nil. Even if it were still here, no one could ever find it."

5.2.1 The ROC and Processes of Reuse

Nadya had worked an attach angle plate job just a few days earlier, so this assembly was fresh on her mind, but she still searched STAIRS for similar cases. She was looking for any special variances on repairs to this part, because she was looking for precedence to help guide the stress analyst's investigation. If she found any, she would place them in the ROC electronic record for later use by the Stress analyst. She commented, however, that "I found a lot [of helpful historic cases], some things that could work. One ref [reference] sounded identical; unfortunately it was old, 1982. Records that old are very incomplete. We'll probably have to do basic analysis unless Samir can find something better. And some times he does. That's the problem with old repairs, old records – rough, vague and sketchy."

It is common practice for both Structures and Stress engineers to scour the archival ROCs for ones that might match their current job. They look for ROCs that can be reused directly, parts that can be used as building blocks to jumpstart a new analysis, or cases which set precedence (i.e., help understand what allowances had been made in the past and under what conditions). Frequently, the engineers are more successful than Nadya was in this case. For her, only one was a close match, and that required too much effort to re-interpret. In our observations, "too old" and "not a good fit" were markers for ROCs that had problematic recontextualization. These would contain "incomplete" information that was either outdated (e.g., because of procedural changes) or inappropriate (e.g., because of shift in conditions, such an operators financial state). In this case, the 1982 ROC was too challenging to re-use as it predated the AD, but in general, analysts would attempt to recontextualize prior ROCs and re-use those they found appropriate.

5.2.2 Finding a Solution

As Nadya prepared the ROC, she explained how the service request would proceed. "[Samir will] check if strength is sufficient with the eleven, compared with the blueprint thirteen. Reed McGovern [the DER] will decide in the end. He'll use Stress' [response] and make a decision. If it is not sufficient, it will be a real mess. They'll [SouthCentral] have to fill and re-drill all the holes. Normally this is not the case though, he approves." She predicted that it would be approved with the eleven. "This [part] is designed so far above one hundred percent [tolerance], you can take out a couple of fasteners, no problem."

As with the first case, the record was then handed off to Stress for analysis. Samir was the Stress analyst assigned to the job. As he started his diagnosis, he first wondered whether this was a preventative or a corrective repair. SouthCentral and Nadya had both omitted this information. Samir, on further reflection, concluded that it was not critical, because the plate was going to be replaced regardless.

In this situation, Samir eschewed the usual stress calculations, reasoning that this configuration had performed without failure for thirty years. In completing his review, Samir was convinced that the eleven fastener configuration was suitable for strength. If there had been problems with the reduced fastener configuration, they would have been discovered before thirty years. We believe that he felt confident that SouthCentral had sufficiently capable maintenance engineers and facilities to have uncovered and reported any problems throughout the aircraft's history. We will return to this in the analysis below.

Samir wrote up his argument in support of a "minor deviation" to the AD, allowing a replacement plate with eleven fasteners. The response was then checked by his supervisor and approved by the DER. From the approved ROC Nadya composed a response to SouthCentral giving the approval.

Again, this was a relatively straightforward case. Although it was a non-standard repair, the participants treated it as relatively routine. That is, the particular situation with mis-drilled holes on the dorsal fin attach angle plate was rarely seen, but dealing with manufacturing exceptions was not unknown.

5.2.3 The not so hidden hand of the FAA

The FAA, though not directly involved with the resolution of this case, indirectly influenced almost every step of the process. First was their procedure for recording manufacturing deviations and their subsequent record keeping (lifetime for the aircraft's operator, ten years for the manufacturer). Second was their system of AD inspections and requirements for the operators. Hand in hand with this were the procedures for evaluating and documenting variations in compliance, placing bounds on the action and reasoning by which Nadya and Samir could resolve the job. Third, the FAA trained DERs check the work and verify that the correct FAA procedures have been followed in reaching the result. Reed signed off on Samir's result on a standard FAA form, the 8110-3, which provided legal coverage for SouthCentral indicating the FAA's review and approval. On the DER, Samir commented "it's up to us [Stress] to decide, if what they [SouthCentral] found is acceptable to us or not… The DER has the authority to say 'minor deviation.'" Lastly, the FAA had stationed a PMI at the SouthCentral's repair facility to ensure that they implemented the repair correctly. (The PMI is internal to the operator, the rough equivalent of the DER at GTS-West.) Samir commented, that "they're tough, but that's their job. Very meticulous, especially on all [parts like this.]"

In the first case, the role of the FSA was important for managing the FAA relationship at the actual repair facility. There, Vincent, as a trusted agent, allowed Kai and Todd to be more flexible with their repair requirements, knowing that he would provide oversight. In this second case, the FSA was not as helpful. Operating as a gatekeeper, he had edited SouthCentral's request to GTS-West, simplifying where he thought appropriate. This was a poor judgment. Nadya spent significant time trying to locating this excised information and reenter it into the record before sending it to Samir. It was her responsibility that the record be complete for the DER's review.

5.2.4 Privileged and problem operators

This non-problematic case highlights a specific kind of contextualization in using the GlobalCOM messages: how relationships between GTS-West and operators are used to interpret, use, and create these boundary objects. The airplanes that GTS-West supports are owned and operated by a very diverse set of organizations: some domestic, some international, some private, some corporate, some large and some operating a single aircraft. In providing customer support, a service engineer at GTS-West gets to know these operators well over the years – their constraints, preferences, helpful and problematic contact people, and so on. Engineers have developed similar understandings of third-party repair facilities, where repairs are outsourced.

Case 2 unfolded with Samir trusting SouthCentral's handling of their aircraft. SouthCentral is one of the largest and most trusted operators of this model family. Nadya and Samir were very familiar with the practices of both the airline and this maintenance facility. This can be observed in Nadya's ability to identify the right person to contact to quickly resolve how the fasteners were spaced. It was also foundational to Samir's final evaluation – if problems with the eleven-fastener configuration had not surfaced in thirty years (implicitly any problems would have been detected by SouthCentral's maintenance crew) then the configuration was clearly suitable for strength.

Not all operators earned the privileged status of SouthCentral. In explaining the above case, Samir described another case he had worked recently with the same AD but a different airline. In a routine inspection, Marita Air, a foreign operator, had found a major crack in the attach angle plate. While this was clearly unacceptable, Samir had no authority to insist on a repair: "Even if we judge it is not safe, we cannot ground the plane. That is not our authority [because it's foreign]." Samir goes on to explain that it was very hard to find a suitable replacement part abroad. The anticipated time for delivery and installation was 240 days. Marita was asking for 1000 flight hours "as-is" to wait for the part, but "at a hundred and fifty flight hours a month, that's six months! That is not acceptable [leaving it unrepaired], not at all."

For this foreign operator, Samir came up with and submitted a temporary repair, which could be approved for six months, just long enough for Marita to get the part. However, he went on to say that he is convinced that they will not order the part now, but instead would procrastinate. They will wait until the six-month temporary expired to order the part. "Then they'll be back in the exact same situation as they are in now, with another 240 day wait from there." He was clearly frustrated: "…It's like a surgeon, you know. He does his job, but you don't do yours. He'll get angry, 'Why'd you let your cancer grow?!?' but that's it, he can't do anything. It is just an objective judgment."

These fine-grained distinctions about operators were not restricted to Nadya or Samir. They were rampant. For example, one airline might request an AOG without describing their context, and they would be believed. Another might be seen as "crying wolf again." The following comment occurred during a heated debate between two Structures and Stress engineers over timeliness and reliability tradeoffs in a particular job. A specific operator, IslandHopper, was constantly submitting AOGs. The comment was intended humorously, but only in part:

> Stress: "If we understand their schedule, they may understand ours. We have other things going on! All theirs' will be R&R with all AOGs. [All of this operator's AOG requests would be treated as 'remove and replace', the most rapid but severe repair strategy.]"

Of course, engineers do not interpret interactions just at the operator level; they do so as well about individuals and maintenance facilities. Indeed, this occurred in Case 1, when Kai requested that Todd talk Beechwood's repair crew through the dimensions for the APU door installation. Kai made this a verbal request rather than mandated in the ROC. He did this because he trusted a Global employee who happened to be on-site to ensure the installation was done correctly. (This was politically less sensitive with the maintenance crew than placing the details of installation in the written record, which would have implied that he believed the repair crew might not be up to the task.)

6.0 CONCLUSIONS

So far, in the above unpacking of the two cases, we have described an organization largely built around bureaucratic assumptions about creating and maintaining safety critical processes. As we have noted, this organization has come under increasing market pressure to resolve more repair requests without increases in staff. The path GTS-West has chosen for these efficiency gains is a greater emphasis on reuse, specifically increasing their reliance on the ROC historical archive. Reuse at GTS-West is tied to the need to decrease costs, but GTS-West must also provide faster solutions all the while maintaining a high degree of safety.

Now we wish to explore the utility of boundary objects, as a theoretical construct, in informing the design of information systems to support organizational memory. The next two sections, in turn, detail the theoretical implications and the transferable design insights that can guide future work.

6.1 THEORETICAL CONTRIBUTIONS

In these two illustrative cases, we identified myriad candidates for boundary objects including maintenance logs, communication archives, regulatory inspectors, and even the aircraft itself. However, three distinct information artifacts were central to the successful reuse practices at GTS-West:

- ROC (historical archive of approved problem resolutions),
- GlobalCOM (structured record of all manufacturer-operator communications),
- 8110 (regulatory approval form for all problem resolutions).

These were the most organizationally complex and theoretically interesting artifacts to examine.

According to Star's (1989) definition all three of these artifacts were strong candidates for classification as boundary objects. (They also met Carlile's (2006) additional requirements of shared language, specification, and transformation.) However, we found in our analysis that the boundary object concept needed to be extended to address three additional considerations. These are discussed next.

6.1.1 Tensions in situated routinization and standardization

Lee (2005) argued that "standardization is integral to the definition of boundary objects" (p. 6). Indeed, much of Star's own later research emphasized the role of boundary objects as instantiations of standardization processes (Bowker and Star, 1999). Yet, our data required a more nuanced, situated view of standardization as a flexible point on a continuum of routinization. Also, in routine work, while the official artifacts and procedures may be organizationally fixed, their use in routine work was quite malleable, to some degree renegotiated with each instance. In short, non-routine work artifacts and processes were made to appear standardized after the fact (Suchman, 1983).

Regarding the standardization of artifacts, all three of the boundary objects described above were the product of well established patterns of interaction between heavily bureaucratic organizations. All were fixed form documents, with keyword vocabularies, check boxes, signature slots, ID numbers, and the like. All had clear, officially sanctioned formal processes regarding their creation, modification, and preservation, for which all employees are routinely trained.

Regarding the standardization of process, in this paper we presented two cases (APU door replacement and fastener reconfiguration) which were not atypical, but also not overly routine. The particulars were unique, but the classes of problem represented were common. The work at GTS-West was a balance between the routine (e.g., corrosion mitigation) and the unique (e.g., lightning strikes). The policies and procedures evolved to service the space in between.

Thus, standardization at GTS-West was always situated in the complex context of everyday work. The institutional arrangements presented a formalized and completely routinized account of the information artifacts and communication process, although the work was anything but. This created numerous tensions that could not be resolved, only managed.

This management is manifest in all of the boundary objects. The 8110 provides one clear example. As discussed earlier, the DER is a unique organizational position – an internal employee, empowered to operate for an external authority in order to regulate internal activity. This allowed Global Airframe to preserve its trade secrets while providing a critical level of redundancy for the high reliability operation of aircraft repair. This also situated the regulatory process within the local experience. When DERs reviewed ROCs, they were privy to any negotiations surrounding the artifact's creation. This knowledge allowed them the flexibility in judgment to regulate the repair process, as captured in the 8110 document. They intimately knew the trustworthiness and specialization of each engineer and analyst, and they shared in the routine office culture which exposed them to the negotiations within which each repair job rested. For example, they shared with the service engineers the knowledge that Marita Air always procrastinated on repairs, that SouthCentral operated one of the most experienced maintenance shops in North America, and that FlyFreedom had a pending ten jet sales order critical to the financial health of Global. They understood which jobs were truly rush "AOGs" and which were just crying wolf.

Some views argue that boundary objects must be standardized, while we found it useful to relax this constraint in interpreting this study. The tension between the routinization and the situatedness of the repair leads to the next theoretical extension, the necessity to view a boundary object as a punctuated crystallization of the repair process at a specific point in time.

6.1.2 Punctuated crystalization

We discussed in previous work that organizational memory is best thought of as both a process and an object (Ackerman and Halverson, 2004; Lutters and Ackerman, 2002). This is clearly the case at GTS-West.

By design, the ROC was supposed to be a static, archival artifact. The dynamic boundary object of the repair request resolution was crystallized at the point of final FAA approval for the repair by the DER. This preserved a limited snapshot of the process' state at that specific point in time.

There was a bit of an organizational myth surrounding the completeness of this snapshot. It was understood that the Stress lead was the final reviewing authority after the DER and was believed to inspect the document in detail before archiving it. This was rarely the case in practice as there was always another pressing repair request in the queue, but it was organizationally important to know that the document had been "vested" by the best and brightest in the department. This provided trustworthiness for the archive. The engineers understood that while repair jobs were routinely double checked, the records that supported them rarely were.

As well, it is important to note that the ROC was archived after the solution was designed and approved by the DER, but before the repair was actually implemented by the operator. Except under exceptional circumstances the archival record was not modified to reflect altered implementations. At the maintenance facility the PMIs, as FAA representatives, allowed minor deviations from the DER approved repairs–accomplishing the repair for the operator within the constraints of their available resources, time frame, and engineering expertise. These subtle modifications were never recorded in the ROC, but were usually communicated back to GTS-West. (These formed the foundation for the shared social understandings of the event streams to be discussed next.)

Boundary objects, as a term, connote a static, archival artifact. However, boundary objects are created within an information flow. Each boundary object is a unique object, but it is also a unique event within an information process. A specific ROC is created as a crystallization at one point in time about an entire situation and its information processes (Shapiro, 1994). It is not a continuous crystallization, but rather one that is punctuated. Moreover, since the ROCs are constantly under interpretation and contextualization in GTS-West, they continue in a process after their crystallization. To properly understand a boundary object's use and reuse with GTS-West, it is important to understand it how it was created and used within its information process. This process not only includes the current situation, however. It also includes past and potentially future repair situations, as will be explored next.

6.1.3 Meta-negotiations and event streams

Boundary objects lie within larger (or meta-) processes, since they translate meaning from one group to another, one composed of all boundary objects from one group to the other. For GTS-West, this meta-process involved the engineers' understanding of such issues as the financial state of the operator, trustworthiness of a third party maintenance facility, experience of the service engineer, NTSB modifications to FAA regulations, history of manufacturing processes, and differing inspection regimes.

This meta-process, then, created an implicit negotiation (or rather, meta-negotiation) about how to interpret and contextualize each individual boundary object. In reality, this meta-negotiation constantly unfolded in the enactment of each request. Thus, understanding the meta-negotiation was key to potential reuse. Yet, how individual boundary objects were to be interpreted was often excluded from the individual objects themselves. Indeed, this was part of the decontextualization process for the organization's bureaucratic procedures.

At GTS-West, we saw that at least the operator's prior history with GTS-West influenced all interactions with and interpretations of the boundary objects in a repair request resolution. That is, a single boundary object was seldom interpreted only within itself; boundary objects existed within a history greater than themselves.

This history consisted of the perpetual negotiations and renegotiations surrounding the boundary objects. As has been seen, the approach to a solution, as represented in the ROC and GlobalCOM records, would shift according to the perception of the operator's expertise, cooperation, and competence. As such, a response to SouthCentral, with their large Global fleet and proven reliability of their regional repair centers, would receive a different response than would Marita. In the IslandHopper example, the Stress engineer threatened to unilaterally change activity around all IslandHopper requests based on his interpretation of their bothersome manner.

Conversely an individual repair request, and its related boundary objects, could alter the stream. An egregious misinterpretation of a repair, intractable maintenance crews, or problematic elicitation of repair information could all sour the internal assumptions about a given airline. This process could also happen in reverse. During the duration of the study the reputation of a South American carrier developed though a series of exceptionally professional jobs to be viewed as more competent than some domestic operators.

The contextualization, based on the service engineer's opinions of operators, not only affected the creation of ROCs (e.g., Kai not assigning the job to Bud), but more importantly, it likely affected later interpretation for reliable reuse. As previously mentioned the ROC, as an organizational memory component, was frequently leveraged for reuse and recontextualizing these historical ROCs could be difficult. In the routine process of decontextualizing the ROC for archive, the details surrounding the ROC creation were removed. The information about the historical stream and its negotiations was often lost, making recontextualization problematic.

To summarize, the three theoretical extensions to boundary objects – loose routinization, punctuated crystallization, and meta-negotiation streams – were required to make sense of our data. While GTS-West is, in many ways, a unique site, we believe these extensions will hold in a large variety of situations where boundary objects can be found. Clearly, not all boundary objects and their concomitant processes are completely standardized. If they are not completely standardized, then it is likely that some form of these findings will hold.

6.2 DESIGN IMPLICATIONS

There are some clear design implications for augmenting these boundary objects within GTS-West. While these boundary objects may be idiosyncratic to GTS-West, it is likely that similar design implications will hold across sites with similar boundary objects.

We focus here on the ROC, as it is the most internal and malleable of the standardized formats. The ROC itself is a workaround. As mentioned, its original purpose was only to meet a regulatory requirement by providing an audit trail of all repair request resolutions. Over time it was appropriated as a repository of repair practices to be mined in order to safely reduce the time and complexity of repair request resolution. It thus became a successful organizational memory system through creative end-user embedding of contextual cues into the official record. Capturing more detail of the negotiation surrounding the job resolution allowed for easier recontextualization and reuse of the record later. This obviates two design criteria, the first technical and the second organizational.

6.2.1 Augment context capture

Within GTS-West, the understandings of the meta-negotiations required for later recontextualization are often too sensitive to write down. In a high-liability environment such as this, any document in the formal or informal paper trail related to each repair job can be subpoenaed for an accident investigation and used to determine potential negligence on the part of GTS. (All of the physical cabinets in the office have solid steel lock plates, a constant visual reminder that the NTSB could take possession of the records at any time.) However, while the specific details of these meta-negotiations may be lost to the record itself, they are not lost entirely from the organization's memory. Annotation moves outside the system. It is done socially.

Thus, a design implication of this study is that it would be useful to find better ways to preserve both pointers into this social memory and to a specific kind of state – so as to augment the ability to recreate the meta-negotiations and relationships at the temporal point where the boundary object was crystallized. One cannot hope to capture all context. Setting aside this impossibility, no one will do it organizationally: As mentioned, the ROC is an audit trail, ripe for legal problems in a safety-critical environment. Nonetheless, simple augmentations may be sufficient.

Necessarily, opinions of operators and others are only part of what GTS-West engineers use to contextualize the GlobalCOM messages and ROCs as boundary objects. We do not mean to imply this is the only issue for engineers in interpreting their work. They also note Global management strictures and

FAA regulations, time pressures, and staffing issues. They may differ in their opinions from their colleagues. Nonetheless, within GTS-West, engineers' views of incoming messages and outgoing phrasings were critical and common enough to their work.

In general, we believe it is possible to augment the memory of the context – by simply signaling key indicators. In the case of GTS-West, this includes operators' or repair stations' conditions at various dates. The inferences are still up to the engineers and analysts; the augmentation merely helps them handle additional complexity. This mirrors an existing practice of embedding pointers to individual engineer's technical journals as a memory shortcut to recall the particular event streams at the time of the records creation.

6.2.2 Organizationally sanction preservation of complexity

The second design implication is organizational. GTS-West already has a strong organizational culture for preserving information and relying on it heavily for reuse. To assist companies like GTS-West in addressing their time to resolution pressures, one can speculate on the institutional rearrangements required to make something like the ROC an integral component of the safety mission itself, not just a creative workaround to the official processes.

Within GTS-West, extensions similar to this have already been attempted. In one case an effort was made to replicate a Global standard process at GTS-West, highlighting some of their organizational reliance on maintaining complex historical records. This simple knowledge management effort was to distill key problem-solution arcs from GlobalCOM into a shared best practice repository. Specific details of the operator, aircraft, and employees were removed and practices employed were generalized. This was a familiar process to GTS-West, it reflected the multi-step iterative design they followed for repair instructions moving from one-of-a-kind ROC to an operator service letter to a fleet wide document to including in their standard repair processes manual.

While this system was reasonably successful elsewhere in Global, it was aborted early on at GTS-West. The rich complexity of the ROC simply provided better support for recontextualization in reuse.

A step mid-way between these two may prove successful in many organizations. This mid-way step would be providing managerial support for identifying teachable best practice cases while preserving the rich contextual detail and embedded cues currently found in actual work artifacts like the ROC.

6.3 SUMMARY

To summarize, then, the two cases showed GTS-West personnel balancing safety, reliability, and timeliness in order to routinely satisfy operators' and GTS's requirements. The service engineers did so by interpreting and contextualizing the critical boundary objects (ROCs, GlobalCOM messages, and 8110 forms) with regard to larger considerations, including the history of interactions with the operators and others. Our analysis of these interactions yielded three primary observations:

- Tensions in situated routinization and standardization: The key boundary objects in this highly standardized work environment were in constant flux, reflecting the shifts in the "routine" work of aircraft repair.
- Punctuated crystallization: The archival boundary objects were discreet snapshots of ongoing processes, capturing the system state at a single point. This point was the regulatory approval of a repair job request, along the interwoven trajectories of aircraft, operators and the airframe manufacturer.
- Meta-negotiations and event streams: Boundary objects were interpreted with regard to the historic and current state of operators' relations with GTS-West. How they had previously responded (and how they were likely to respond) formed event streams. Successful recontextualization and reuse hinged upon an understanding of these event streams.

In our site, we discovered these boundary-spanning phenomena to be more complex than other reports of boundary objects. While we still found Star's boundary objects to be the best available theoretic fit for understanding reuse at GTS-West, in this paper, we needed to extend it by discussing the various processes that surround the boundary object itself.

This study also provided hope that one can uncover the meta-negotiation information in the event stream to supplement boundary objects for later use. We note that results from field studies cannot be easily generalized, and indeed GTS has a rather unique organizational culture. However, based on the findings here, there were two significant implications for design:

- Augment context capture: There is a balance between automatically capturing all available contextual information (yielding an unmanageable repository) and capturing none (supporting the security required in this high-liability work setting). In this particular environment it would be useful to provide flags about meta-negotiations in the record as well as embed pointers to GTS-West people who served as their distributed system of social annotation.
- Support preservation of complexity: For some processes, preserving complex boundary objects "whole" is more valuable than reifying them into best practices as it provides more contextual hooks for later recontextualization. This was particularly true for the engineering records in GTS-West.

At GTS-West, these design improvements would allow service engineers to more easily reuse parts of its organizational memory. In other companies, perhaps with safety imperatives or with simplified information flows, we believe it likely that we can find other, similar meta-negotiations occurring.

Based on this work, future investigations should include additional reports on boundary objects and their meta-negotiations. The various boundary objects, memory processes, and meta-negotiations may form a more complex object to investigate, one we are calling *boundary processes*. As well, we ae conducting additional investigations into the uses, as well as augmentations, of boundary objects in information reuse.

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[1] We use “theoretical concept” in this paper to connote Strauss’ grounded theory use in furthering analysis and understanding, rather than to invoke Parsonian-like grand theories.
[2] The APU is a small turbine engine used to generate electricity while the airplane is not in flight. Its primary purpose is to act as a starter for the main jet engines and run lighting and environmental systems while on the ground.