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ABSTRACT

Communication issues persist in sociotechnical systems with functioning communication equipment, prompting researchers and practitioners alike to bemoan the absence of information sharing. Computer scientists envision a broadly accessible virtual display, but lack the principles for selecting, formatting and organizing content to make it useful. We argue that what is needed is information rather than data, and that situating data in context is key to the provision of information. Documentation of information exchange issues in real crisis management is quite superficial, generally pointing to conclusions without any supporting data. Using documentation of the Deepwater Horizon Accident in 2010, we suggest three requirements for the design of computationally supported information exchange: 1) computational support to distribute distilled information, not low-level data, 2) a computationally accessible, current plan to provide context to guide the routing of information to interested parties and 3) a means to detect and elevate newly relevant, but formerly suppressed detail.

Keywords

Communication, information sharing, virtual information display.

INTRODUCTION

Communication is an important factor in socio-technical systems, particularly during emergencies related to natural disasters, terrorist attacks, or combat. Recognizing this, the crisis management literature focuses on improving the integrity of communication equipment, vulnerable for example to the loss of electricity or communication satellites. Though the integrity of communication equipment is surely necessary, this is but one factor in effective communication. Communication issues arise even in the presence of functioning communication equipment, generally attributed to the absence of information sharing. Quarantelli (1986) is a prominent voice in this realization, pointing to the need for rapid and accurate communications in crisis management. Lagadec (2007), Dautun (2007), Karsenty (2015) and Weick (1995) enrich our understanding, pointing out problems specific to crisis management such as the unexpected nature of events with extensive consequence and the need for a several teams of response experts representing many different but interacting domains with their own concerns, organizations and cultures (e.g., health and utilities). The complaints regarding communication challenges are numerous, but the theory of effective communication is thin and vague, lacking in constructs to guide analysis and remedy. For example, Lee & Seppelt (2012) consider the interaction with automation as a communication problem, but still rely on constructs founded on the properties of an individual, human information processing architecture. More recently, Projet GénéPi (Granularité des Niveaux de Pilotage en Gestion de Crise, 2015) identifies the importance of context in the interpretation of crisis data; data do not have persisting relevance, affected by the passage of time and human intervention. For example, a road may not stay flooded indefinitely, and debris eventually gets removed. Context is not an issue that emerges from a human information processing perspective; this is an issue that emerges from domain analysis including the influence of, and interaction between, multiple agents with different responsibilities. Our goal here is to reveal exactly what "context" means, to assure that context is preserved in any attempts to remediate communication issues with computational tools.

While the literature is full of conclusions, the actual data regarding information distribution issues during a crisis is quite sparse and therefore lacking in implementation implications. This paper provides specific examples to illustrate general claims regarding the nature of context. Our examples are drawn from the explosion that occurred on the Deepwater Horizon oil rig on April 20, 2010, in the Gulf of Mexico, well documented in widely available US government reports. Our concern here, however, is not the resulting crisis, however tragic. Rather, as a result of the crisis, extensive documentation of the preceding events provides an unusually detailed, publically accessible account of the communication work practice in complex distributed socio-technical systems. Daily work practice on Deepwater Horizon has most of the critical properties of crisis management noted above, including unexpected events, extensive consequence, the involvement of numerous disciplines with diverse responsibilities, and a key role for context in the interpretation of data.

Although we note limited scholarly analysis regarding either computational capability or human behavior in the available documentation of Deepwater Horizon, we do not attempt to re-assess responsibility nor take a position on sensitive policy matters. We do however take issue with the superficial claim that *"there is no apparent reason why more sophisticated, automated alarms and algorithms cannot be built into the display system to alert [...] anomalies."* Figure 1 betrays a profound mis-appreciation for the human role in such complex socio-technical systems and the challenge of data interpretation in a noisy, stochastic and generally successful work practice in which the base rate of nominal conditions vastly outnumbers the base rate of consequential, off-nominal conditions (see Moray, 2003 regarding the cost-effective human response to automation). Revealing the true human role in the interpretation of data and the exchange of information, particularly concerning context sensitivity, provides a proper foundation for computational tools for information exchange.

> "In the future, the instrumentation and displays used for well monitoring must be improved. There is no apparent reason why more sophisticated, automated alarms and algorithms cannot be built into the display system to alert the driller and mudloggers when anomalies arise. These individuals sit for 12 hours at a time in front of these displays. In light of the potential consequences, it is no longer acceptable to rely on a system that requires the right person to be looking at the right data at the right time, and then to understand its significance in spite of simultaneous activities and other monitoring responsibilities."

Figure 1. Commission impression of human fallibility in sociotechnical systems (National Commission, 2011a, p.121).

Consistent with Hong & Page (2008), we claim that a primary responsibility of humans is to *interpret* data with knowledge, and distribute these interpretations to other participants whose subsequent or simultaneous activities depend on these interpretations. Humans do not function like sensors (Sheth & Thirunarayan, 2012; Hampton & Shalin, 2017) but rather use knowledge and experience to place their observations in the context of work goals and responsibilities. Participants in a complex domain differ not only in work goals and responsibilities, but also knowledge and experience, and are therefore differentially sensitive to particular features of the world. Observers share information (rather than data) and so must our communication tools. However, in distributed and/or mediated work, participants do not share responsibilities, access to the same data or knowledge to interpret the data. As a result, we claim that shared information is tailored in detail (Wilson & Sperber, 2004) according to the anticipated needs of a trusting recipient. This paper aims to illustrate the process of transforming data into information by situating them in context, resulting in the suppression of reasoning details in the transmission of conclusions; the necessarily evolving work plan provides a key component of context; and previously suppressed domain-specific details take on importance in the interpretation of new data. We employ data from the President's commission, a separate report of recommendations, and C-Span video testimony to provide a qualitative analysis. In so doing, we expose the key challenge in the development of computational support for the distribution of information: to maintain and complement the fundamentally context-sensitive features of communication.

THE DEEPWATER HORIZON ACCIDENT

On April 20, 2010, the Deepwater Horizon (a mobile drilling platform such as show in Figure 2) dug the deepest well ever offshore in the Gulf of Mexico. A resulting explosion caused a fire that killed 11 and injured 17. The event was subject to extensive investigation, including an independent U.S. White House commission of inquiry and the U.S. House Energy and Commerce Committee. Investigation identified some clear areas of concern regarding risk management and construction oversights. We employ the report from the President's commission (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling (2011a)[1], informed by National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling (2011b) and the Committee on the Analysis of Causes of the *Deepwater Horizon* Explosion, Fire, and Oil Spill to Identify Measures to Prevent Similar Accidents in the Future (2012)[2], and C-Span video testimony[3] as indicated below.

Figure 2. **Mobile oil drilling rig positioned on a drilling site.**

According to the National Commission Report (2011a, p.76) British Petroleum (BP) contracted with Transocean for the services of the Deepwater Horizon mobile offshore drilling rig to conduct drilling operations at the Macondo well site in the Gulf of Mexico, off the Louisiana US coastline. BP contracted separate services for cementing from Halliburton, well data logging from Sperry Sun, well and cement logging services from Schlumberger and services from several other companies of tangential interest to this paper.

While problem solving often proceeds by decomposing potentially separable elements into sub-problems, the approach is merely heuristic (Simon, 1962). Complex systems are only "nearly" decomposable, and potential dependencies eventually require evaluation. Snook & Connor (2005, p.196), notes NASA's failure to recognize the cross-disciplinary foam strike problem that doomed STS-107. *"Whatever you divide, you have to put back together again."* (Snook & Connor, p.199). In particular, we are concerned with the distribution of responsibilities across multiple contractors with different organizational cultures. This is characteristic of sociotechnical systems, including crisis management. We will see below that re-assembly depends on the communication of information between tasks rather than data.

Our analysis of communication problems in socio-technical systems (Linot, Dinet, Charoy & Shalin, 2018) takes inspiration from several sources. Pickering & Garrod's (2004) model of verbal exchange between two participants emphasizes a generic goal of communication, to establish aligned situation models. However, Pickering and Garrod omit several constructs that we believe are important in a model that serves the development of information technology. First, and emphasized here, we add a distinction between observable features in the world (data) and the resulting information. Information results from interpretive, knowledge based processes. Drawing from Mayer et al (1995), we consider propensity to trust, risk perception and evaluation, which we believe influences interpretive processes and information exchange. The recipients of information may lack the knowledge required for interpretation. Because detail is intentionally omitted in this exchange, trust is fundamental to the process. Recipients must trust in the source to provide comprehensible, relevant content, enhancing what Endsley (1995) calls *"situation awareness"*. Complimenting Pickering & Garrod, we include a role for communication tools, which must preserve communication goals for alignment founded on trust.

IMPLICATIONS OF DEEPWATER HORIZON FOR THE DESIGN OF COMPUTATIONAL SUPPORT FOR COMMUNICATION

Recipients in the exchange of information trust their sources to tell them everything they need to know, and nothing more (Grice, 1967; Wilson & Sperber, 2004). Below we sample the Deepwater Horizon data to make three related points to guide an implementation of tools that respect this over-arching property of information exchange. First, information is contextualized data. We require computational support to distribute distilled information, not low-level data. An interpretive process necessarily suppresses otherwise overwhelming detail

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[1] Hereafter referred to as the National Commission (2011a) report.

[2] Hereafter referred to as the Committee on the Analysis of causes report.

hidden within the responsibilities of separable disciplines. Second, a key part of context is the work plan, which almost certainly changes in response to emergent circumstances. We require a computationally accessible, current plan to provide context to guide the routing of information to interested parties. Finally, suppressed detail can become newly important with respect to an evolving plan. We require a means to detect and elevate newly relevant, but formerly suppressed detail in the design of computational support for communication.

To select the examples we report here, we reviewed the cited investigation reports, and viewed the publicly available testimony. Our method does not follow anthropologically rigorous grounded theory, in the sense of elevating subtle issues that emerge from systematic analysis of an extensive corpus. Instead, our examples and analysis specifically respond to the quote in Figure 1, to challenge a misguided "alarm" model of information exchange in socio-technical systems. Our sampling method does not establish the base rate for the phenomena we identify in the domain we are studying or for domains in general. We assert, but cannot demonstrate, that the phenomena we note are representative of nominal operations. Skeptics should consider the coding exercise that a compelling quantitative demonstration entails, and its dependence on the scope and detail of the source account outside our control. However, more consistent with the anthropologist's challenge, we frame our interpretation of specific events with a potentially generalizable account to infer their implications for the design of computational support for communication.

Information is contextualized data

A key point of our analysis is that exchanged information, whether during a crisis or nominal operations, is not data, but an interpretation of the data that turns it into information. Figure 3 presents an excerpt from the testimony of Andrea Fleytas, a 23-year-old female responsible for navigating the mobile drilling rig. She was stationed on the vessel bridge, remote from drilling operations. Ms. Fleytas was responsible for monitoring and acknowledging alarms for the engines, ballast control and combustible fire, and was to inform senior officers of any issues.

E: […] their only words to you were **"we are in a well control event"**
W: Yes, they said **"we have a well control situation"** and they hung up.
E: And shortly thereafter you had a call from the engine control room asking you what was going on?
W: That's right. I responded **"we have a well control situation"**
[…].
W: before the phone call I got a, **we were getting the combustible gas alarms**.
[…].
W: **There were so many alarms, there were hundreds of them on that page.**

Figure 3. Andrea Fleytas Testimony (22:24) US Coast Guard & Bureau of Ocean Energy Management. October 5, 2010.

Figure 3 illustrates the distinction between data and information. In this case, the data are the combustible gas alarms. But the information is what this means, that is "*a well control situation"*. While Ms. Fleytas received the data from her control panel on the bridge, the information came from elsewhere. When she received a subsequent inquiry from the engine control room what she reported was not the data, but the information she had received, "*we are in a well control situation*". Unfortunately, a key piece of context was not exchanged – the location of the alarms, potentially due to alarm cacophony.

Although Ms. Fleytas recounts an exchange during the unfolding crisis, we propose that turning data into information is characteristic of all exchange. This is particularly challenging when artifacts are the source of data. Figure 4 illustrates this interpretive problem, for the ordinarily routine problem of determining well-flow. Figure 4 indicates some of the logic required to turn flow data into information: the assumptions, the dependence upon the specific well, and a preference for a particular data source.

W: The flow out meter that Sperry Sun has, I believe it is an acoustic meter. **The flow out meter that Transocean has is a paddle.** They are both relative readings that are calibrated by, you know, seeing how much pump and how much goes into the pit. **It has to be calibrated.** The top line number on there, your flow in, is a calculated number. It is not measured. **It is calculated** from pump strokes **assuming a pump stroke efficiency**.

[…]

W: In Deepwater wells **the main thing you look for is flow back signature. It's called fingerprinting.** So, you see, when you make a connection, since you are using compressible fluid, you see how long it takes the flow to dissipate and does it flow down and level off. And then you time this. And **depending upon the well you are on** you know it could be 2 ½ minutes, it could be ten minutes. Every trip I went out there, and there were many, and I was talking to any of the folks on the rig, **they were always watching the Transocean flow out meter.**

[…]

E: You think even calibrated that the system that Sperry Sun was not as good as the system that Transocean had?

W: That was the feedback I got from the guys on the rig.

Figure 4. John Guide Testimony (1:01:42) US Coast Guard & Bureau of Ocean Energy Management, October 7, 2010.

Figure 5 shows that different cultures may disagree on the merits of different data sources. This extended testimony further illustrates the complex logic of sensor interpretation, in particular, the purpose of the sensor. In addition to confirming the calibration issue raised in Figure 4, Figure 5 raises additional concern for the role of context in sensor interpretation. Calibration is an activity specific to all sensors; recipients of sensor data could reasonably be expected to ask about the recency of calibration. The concern here is that numerous external, common sense events can affect sensor readouts, including crane operations and fluid movements between pits. Operators are responsible for manually logging common sense context, such as which pit is active. Without this information, sensor data are just that, and not information. Figure 5 also disposes of the idea that more alarms will solve the situation awareness problem; they merely add noise because their interpretation is context sensitive.

Although adjudicating between the Sperry/Transocean preferences may be relevant to the accident investigation, it is not relevant here. Different organizations may have different experiences and ownership in different, legitimate data sources. This is one basis of cultural differences between organizations. Most obviously, the observer must understand how the sensor works. Confidence in the resulting interpreted information comes from knowing how it was determined. Second, sensor values reflect a closed world assumption independent of other mitigating factors. However, sensors function in an open world, under the influence of many other factors that affect interpretation. Crucially, the world is not necessarily instrumented to take all of these influences into account in the automated processing of such data. Human observers are aware of these however, and adjust the sensor processing and interpretation accordingly. Therein lies the critical challenge of computationally supported information distribution. Trust is a function of the data source and the logic used to interpret it, but at least some interested parties likely lack the knowledge to conduct interpretation themselves. Moreover, recording the context such as pit activity in machine readable fashion is burdensome.

W: Uh, the flow out sensor that Sperry used was as I mentioned was the sonic sensor. It determines fluid levels, fluid height, the flow return line. […] I don't know the sonic, sorry, I don't know the Transocean model name that they used for their flow out sensor. I just know that it's type was of a paddle.
E: And of the two, which one would you think is the most accurate method or sensor?
W: **I would say the sonic or radar sensor that detects the fluid levels has a greater ability for detecting minute flows**, small flows whereas the paddle does not. Sperry moved to the sonic sensor, they used to employ the paddle sensor, some years ago.
E: […] Mr. Guide he indicated that […] he felt that the **crew relied more on the Transocean paddle type sensor.**
W:[…] **It was their sensor. I expect they would trust their sensor.**
[…]
W: **But the flow out was never intended to be an actual measure of volume. If you want to see the volume, the actual amount of a gain or loss, you would always use the pit volumes. You would never use the flow out over a given time.**
[…] If you have a good calibration then you can expect over a period of time for it to be relatively accurate. But that calibration is in need of constant tweaking. **That's because the flow-out sensor is influenced by so many activities.** Just rig movement will affect your flow out reading, whether it is rig movement due to crane operations or ballasting, or sea movement. […] they **would calibrate them according to whatever rig activities were going on at the time. So, if they were drilling say during crane operations and the crane operations were throwing their flow out sensor off, they might try to recalibrate then.**
E: […] Earlier when I asked you about flow in and flow out you said you would actually have to look at the pit volumes. **How do you do that when you simultaneously have multiple activities going on in the rig? When you are moving fluid from multiple pits to another pit?**
W: **It's difficult.** Um if they are transferring fluid to what is determined to be the active pits at the time, or removing fluid from the active pits, then **it becomes difficult to determine what influences on that active pit are due to that fluid transfer and what influences are due to drilling conditions.** So, if you are say transferring fluid to the active system and you are at the same time taking a gain from the well, it's difficult to determine that gain because you don't know the exact rate of the transfer. The pump system that moves fluid from one pit to another is not monitored for flow. […] **And it is up to the mudloggers to designate in the system which pits are active at the time. For the majority of time pits 9 and 10 were deemed active. But if the rig were to switch to say pit 6 then the mudloggers would go into his system and say 9 and 10 are no longer the active and go into the auxiliary book and designate pit 6 as the active.** And that would be reflected in the actual pit volume change.
[…]
E: And are there alarms on each one of those sensors in case there is a noticeable difference in volumes between the two?
Well, the Sperry system has the capability of setting up an alarm for any data that is stored in its database. So, the mudloggers will typically set up an alarm for what is deemed to be critical information, to see if it would cross certain thresholds or to see if they are not receiving data within a certain time period. So, for instance, gas. If gas were to exceed a certain threshold, the computer would give a visual and an audio alarm. So, the mudloggers, if he hears this, say he is examining a sample, he hears an alarm go off, he can look at his computer and see what crossed what threshold. Typically, there is not an alarm on the flow in or the flow out, **because they vary so often and they stop and start so often. You would have alarms going off every five minutes, every hour.**

Figure 5. John Gisclair Testimony (5:08) US Coast Guard & Bureau of Ocean Energy Management, October 7, 2010.

An (evolving) plan provides essential context

We have already made the claim that information is data placed in context. Here we make the point that the plan—the purpose of the coordinated work along with how it will be achieved, provides this context. Figure 6 presents the plan as represented and distributed in text.

At 10:43 a.m., **Morel e-mail an "Ops Note" to the rest of the Macondo team listing the temporary abandonment procedures for the well. It was the first time the BP Well Site Leaders on the rig had seen the procedures they would use that day.** BP first shared the procedures with the rig crew at the 11 a.m. pre-tour meeting that morning. The basic sequence was as follows: 1. Perform a positive-pressure test to test the integrity of the production casing; 2. Run the drill pipe into the well to 8,367 feet (3,300 feet below the mud line); 3. Displace 3,300 feet of mud in the well with seawater, lifting the mud above the BOP and into the riser; 4. Perform a negative-pressure test to assess the integrity of the well and bottom-hole cement job to ensure outside fluids (such as hydrocarbons) are not leaking into the well; 5. Displace the mud in the riser with seawater; 6. Set the surface cement plug at 8,367 feet; and 7. Set the lock down sleeve.

Figure 6. The final plan for temporary well abandonment. Step four was not properly conducted (National Commission, 2011a, p. 104).

First, we note that plan steps provide the language of communication. Figure 7 summarizes the exchanges surrounding step 1, the positive pressure test for casing integrity.

Once the pumps were off, a BP representative and Vincent Tabler of Halliburton performed a check to see whether the float valves were closed and holding. They opened a valve at the cementing unit to see whether any fluid flowed from the well. If more fluid came back than expected, that would indicate that cement was migrating back up into the casing and pushing the fluids above it out of the top of the well. Models had predicted 5 barrels of flow back. According to Brian Morel, the two men observed 5.5 barrels of flow, tapering off to a "fingertip trickle." According to Morel, 5.5 barrels of flow-back volume was within the acceptable margin for error. Tabler testified that they watched flow "until it was probably what we call a pencil stream," which stopped, started up again, and then stopped altogether. While it is not clear how long the two men actually watched for potential flow, they eventually concluded the float valves were holding. With no lost returns, BP and Halliburton **declared the job a success.** Nathaniel Chaisson, one of Halliburton's crew on the rig, sent an e-mail to Jesse Gagliano at 5:45 a.m. saying, **"We have completed the job and it went well." He attached a detailed report stating that the job had been "pumped as planned" and that he had seen full returns throughout the process. And just before leaving the rig, Morel e-mailed the rest of the BP team to say "the Halliburton cement team . . . did a great job."**

Figure 7. Information exchange reflects the steps of the plan (National Commission, 2011a, p. 90).

The information to be exchanged is not decontextualized flow-back volume and its change over time, but the status of completing a procedural step, and its implications for the success of the prior cement job. We see the same type of high-level language in communication regarding the success of step 4, in figure 8.

At 8:02 p.m., the crew opened the annular preventer and began displacing mud and spacer from the riser. Halliburton cementer Chris Haire went to the drill shack to check on the status of the upcoming surface cement plug job. Revette and Anderson told him the **negative-pressure test had been successful and that Haire should prepare to set the surface cement plug,** (p. 109).
Senior Toolpusher Randy Ezell left the evening meeting with BP feeling pleased at their praise "on how good a job we had done…How proud they were of the rig. "He stopped in at the galley to get a beverage before continuing to his office. At 9:20, he called Anderson up on the rig floor and asked", "**How did your negative test go?"65 Anderson: "it went good".** We bled it off. We watched it for 30 minutes and we had no flow." Ezell: "**What about your displacement**? How's it going?" Anderson: "It's going fine […] It won't be much longer and we ought to have our spacer back." [...], (p. 7).

Figure 8. Two accounts of the status of negative pressure test (step 4) in preparation for surface plug setting (step 6). As described later in the report a spacer is a liquid that separates drilling mud used during the drilling operations from the seawater that is pumped in to displace the mud once drilling is complete, that is a reference to step 5 (National Commission, 2011a).

We suggest that these are nominal exchanges between professionals with different specialties. Some detail behind the conclusion might be articulated, but certainly not all. *In the nominal case*, the abbreviated account is a necessity in distributed work, without which participants would be mired in endless speculation. The recipient needs to know whether the prerequisite step has been completed, and that is the focus of communication. Consistent with Gricean communication principles (1967) and Cooke et. al (2009) who show that more information is not necessarily better, participants trust other participants to provide important information. If observers omit detail, recipients are justified in assuming that the omitted detail is not relevant; the absence of report implies the absence of import.

A further challenge lies in plan changes (see Figures 9, 10 and 11).

While initial well design decisions undergo a serious peer review process and changes to well design are subsequently subject to a management of change (MOC) process, **changes to drilling procedures in the weeks and days before** implementation are typically not subject to any such peer-review or MOC process. At Macondo, such decisions appear to have been made by the BP Macondo team in ad hoc fashion without any formal risk analysis or internal expert review. This appears to have been a key causal factor of the blowout. A few obvious examples, such as the last-minute confusion regarding whether to run six or 21 centralizers, have already been highlighted.

Figure 9. Documentation of frequent changes in the plan (National Commission, 2011a, p. 122).

While accident analysis focuses on the absence of change management protocols, our point is that the plan always changes in response to prevailing circumstances. Because the plan provides important context for the interpretation of information, communicating plan changes becomes relevant, as does re-situating data previously conceptualized in terms of a now stale plan.

The evidence to date does not unequivocally establish whether **the failure to use 15 additional centralizers** was a direct cause of the blowout. But the process by which BP arrived at the decision to use only six centralizers at Macondo illuminates the flaws in BP's management and design procedures, as well as poor communication between BP and Halliburton. For example, it does not appear that BP's team tried to determine before April 15 whether additional centralizers would be needed. Had BP examined the issue earlier, it might have been able to secure additional centralizers of the design it favored. Nor does it appear that BP based its decision on a full examination of all potential risks involved. Instead, the decision appears to have been driven by an aversion to one particular risk: that slip-on centralizers would hang up on other equipment. **BP did not inform Halliburton of the number of centralizers it eventually used**, let alone request new modeling to predict the impact of using only six centralizers.

Halliburton happened to find out that BP had run only six centralizers when one of its cement engineers overheard a discussion on the rig.

Figure 10. Plan changes associated with the number of centralizers (National Commission, 2011a, p. 115-116).

Another clear example is provided by the temporary abandonment procedure used at Macondo. As discussed earlier, **that procedure changed dramatically and repeatedly during the week leading up to the blowout**. As of April 12, the plan was to set the cement plug in seawater less than 1,000 feet below the mud line after setting the lockdown sleeve. Two days later, Morel sent an e-mail in which the procedure was to set the cement plug in mud before displacing the riser with seawater.

By April 20, the plan had morphed into the one set forth in the Ops Note": the crew would remove 3,300 feet of mud from below the mud line and set the cement plug after the riser had been displaced.

Figure 11. Additional plan changes in temporary abandonment procedure (National Commission, 2011a, p. 123).

The integrity of the cement job is crucial, indicated in Figure 12, and echoed in the report "Given the risk factors surrounding the primary cement job" (p. 119), including a change in cement materials (National Commission, 2011a).

> BP's overall approach to the centralizer decision is perhaps best summed up in an e-mail from BP engineer Brett Cocales sent to Brian Morel on April 16. Cocales expressed disagreement with Morel's opinion that more centralizers were unnecessary because the hole was straight, but then concluded the e-mail by saying. **But, who cares, it's done, end of story, [we] will probably be fine and we'll get a good cement job.** I would rather have to squeeze [remediate the cement job] than get stuck above the WH [wellhead]. So Guide is right on the risk/reward equation.

Figure 12. Additional plan changes to cement job (National Commission, 2011a, p. 116).

Suppressed Details can Matter

The fatal error concerns the determination of a successful negative-pressure test, resulting from two different types of problems: 1) proximal errors concerning the logic surrounding the declaration and 2) distal errors concerning the absence of relevant context to guide the interpretation of negative test data.

Logic surrounding the negative pressure test

Figure 13 explains the general idea behind the test.

> Instead of pumping pressure into the wellbore to see if fluids leak out, the crew removes pressure from inside the well to see if fluids, such as hydrocarbons, leak in, past or through the bottom hole cement job. In so doing, the crew simulates the effect of removing the mud in the wellbore and the riser (and the pressure exerted by that mud) during temporary abandonment. If the casing and primary cement have been designed and installed properly, they will prevent hydrocarbons from intruding even when that "overbalancing" pressure is removed. First, the crew sets up the well to simulate the expected hydrostatic pressure exerted by the column of fluids on the bottom of the well in its abandoned state. Second, the crew bleeds off any pent-up pressure that remains in the well, taking it down to 0 psi. Third, the crew and Well Site Leaders watch to make sure that nothing flows up from and out of the well and that no pressure builds back up inside of the well. If there is no flow or pressure buildup, that means that the casing and primary cement have sealed the well off from external fluid pressure and flow. A negative-pressure test is successful if there is no flow out of the well for a sustained period and if there is no pressure build-up inside the well when it is closed at the surface.

Figure 13. Logic of the negative pressure test (National Commission, 2011a, p. 105).

Figure 14 describes what actually happened. We see here what is by now the crucial communication feature. The information is in terms of the plan for abandonment, a successful negative pressure test. Spectacularly problematic logical details are suppressed. The above documentation in Figure 8 reveals that the conclusion and not the details get distributed through the work system.

According to outcome, the crew was clearly wrong in their conclusion. Additional documentation (see Figure 15) distributes the flawed proximal reasoning across both BP and Transocean personnel, (National Commission 2011b, p. 240). Figure 16 further documents a failure to seek additional input from on-site expertise.

The crew opened the drill pipe at the rig to bleed off any pressure that had built up in the well during the mud-displacement process. The crew tried to bleed the pressure down to zero, but could not get it below 266 psi. **When the drill pipe was closed, the pressure jumped back up to 1,262 psi.**

[…]

BP Well Site Leader Vidrine then insisted on running a second negative-pressure test, this time monitoring pressure and flow on the kill line rather than the drill pipe. (The kill line is one of three pipes, each approximately 3 inches in diameter, that run from the rig to the BOP to allow the crew to circulate fluids into and out of the well at the sea floor.) The pressure on the kill line during the negative pressure test should have been identical to the pressure on the drill pipe, as both flow paths went to the same place (and both should have been filled with seawater). Vidrine apparently insisted the negative test be repeated on the kill line because BP had specified that the test would be performed on the kill line in a permit application it submitted earlier to MMS. For the second test, the crew opened the kill line and bled the pressure down to 0 psi. A small amount of fluid flowed, and then stopped. Rig personnel left the kill line open for 30 minutes but did not observe any flow from it. **The test on the kill line thus satisfied the criteria for a successful negative pressure test—no flow or pressure buildup for a sustained period of time.** But the pressure on the drill pipe remained at 1,400 psi throughout. The Well Site Leaders and crew **never appear to have reconciled the two different pressure readings.**

[A] “bladder effect” may have been proposed as an explanation for the anomaly—but based on available information, the 1,400-psi reading on the drill pipe could [..] only have been caused by a leak into the well. Nevertheless, at 8 p.m., BP Well Site Leaders, in consultation with the crew, made a key error and mistakenly concluded the second negative test procedure had confirmed the well’s integrity. **They declared the test a success** and moved on to the next step in temporary abandonment.

Figure 14. The negative pressure test was declared successful for the kill line instead of the drill line, (National Commission 2011a, p. 107/108).

BP and Transocean have sparred since the blowout regarding the relative competence of Transocean rig workers [I.E., Anderson] to interpret negative pressure test data. [...] BP personnel **certainly believed that Transocean personnel were not only competent to interpret those test results, but experienced and worthy of consultation**. [...] BP’s well site leaders appear to have accepted a facially implausible explanation of the negative pressure test results from Transocean personnel. [...] Transocean **personnel were experienced and the BP well site leaders thus believed they could rely on Transocean personnel**. [BP personnel] Kaluza and Vidrine both appear to have **deferred to Transocean tool pusher Jason Anderson’ s experience**. And Guide told the Chief Counsel’s team emphatically that the **Transocean personnel were in fact capable and competent** to recognize the problems with the well during the negative pressure test. [...] Transocean agrees that its crew is expert in monitoring for and identifying kicks, even in underbalanced situations. Hence the rig crew did not call the BP well site leaders for advice when they noticed anomalous pressure readings during the displacement of the riser but instead relied on their own expertise to determine whether there was a kick.

Figure 15. Distributed responsibility for flawed reasoning proximal to event (National Commission, 2011b, p. 240).

Trust in personnel judgment is key to the proliferation of a flawed conclusion. A final concern is the availability of information to raise suspicion regarding the anomaly.

Information about drilling at Macondo was compartmentalized both within and between companies. It does not appear that the well site leaders ever contacted BP onshore personnel to discuss their inability to bleed off drill pipe pressure during the negative pressure test. They did not seek a second opinion from Sims or O’Bryan, both of whom are engineers and were on the rig during the negative pressure test as part of the VIP visit. Instead, according to their own accounts, the well site leaders accepted an explanation from a Transocean tool pusher who had no more training on test procedures than they had (p. 228).

Figure 16. Additional experts were not consulted (National commission 2011b).

The pressure data were not ambiguous. Rather, they showed repeatedly that formation fluids, in this case hydrocarbons, were flowing into the well. **The failure to properly conduct and interpret the negative-pressure test was a major contributing factor to the blowout.** Given the risk factors surrounding the primary cement job and other prior unusual events (such as difficulty converting the float valves), the BP Well Site Leaders and, to the extent they were aware of the issues, the **Transocean crew should have been particularly sensitive to anomalous pressure readings and ready to accept that the primary cement job could have failed.** It appears instead they started from the assumption that the well could not be flowing, and kept running tests and coming up with various explanations until they had convinced themselves their assumption was correct. Finally, due to poor communication, **it does not appear that the men performing and interpreting the test had a full appreciation of the context in which they were performing it. Such an appreciation might have increased their willingness to believe the well was flowing** (p. 119).

Information appears to have been excessively compartmentalized at Macondo as a result of poor communication. BP did not share **important** information with its contractors, or sometimes internally even with members of its own team. Contractors did not share **important information** with BP or each other. As a result, individuals often found themselves making critical decisions without a full appreciation for the context in which they were being made (or even without recognition that the decisions were critical). For example, many BP and Halliburton employees were aware of the difficulty of the primary cement job. But those issues were for the most part *not* **communicated to the rig crew** that conducted the negative-pressure test and monitored the well. It appears that BP did not even communicate many of those issues to its own personnel on the rig—in particular to Bob Kaluza, who was on his first hitch as a Well Site Leader on the Deepwater Horizon (p. 123).

Figure 17. Distal contributions to the accident (National Commission 2011a).

Absence of Contextual Information

We have already argued about the challenge of interpreting anomaly, for example in well flow rates due to the role of context. This is why alarms do not solve the information distribution problem. Figure 17 summarizes the distal context that should have influenced the interpretation of the anomalous negative pressure test data.

In this case, trust in the system to distribute relevant contextual information was badly misplaced, a likely reflection of organizational cultures at BP, and contributing to misalignment between subcontractors. Several procedural changes, many of which were either unknown or not salient, and some of which occurred well prior to drilling activity, constituted context that should have raised suspicion regarding the results of the negative flow test. These include: changes in the well equipment, reducing the number of centralizers employed (National Commission, 2011a, p. 116), changes in the composition of well cement (National Commission, 2011a, p. 117), the absence of a final cement test (National Commission, 2011a, p. 117), changes to the cements procedure (National Commission, 2011a, p. 120; National Commission, 2011b, p. 233), ambiguity regarding the adequacy of the float valves (National Commission, 2011a, p. 98) and changes to the procedure for conducting the negative flow test (National Commission, 2011a, p. 108).

CONCLUSION

The outcome of Deepwater Horizon is too easily dismissed by blaming less than admirable profit motives. Moreover, such a conclusion has little bearing on crisis response. While "poor communication" accurately labels the phenomena contributing to the Deepwater Horizon accident, the label does little to reveal the general principles one might employ to design computational tools that effectively support communication.

To this end we have made three related points in this paper: Data become information by situating them in context resulting in the suppression of reasoning details in the transmission of conclusions; the necessarily evolving work plan provides a key component of context; and previously suppressed domain-specific details take on importance in the interpretation of new data. Organizational culture likely influences both the interpretation processes and the scope of information detail to be exchanged between organizations. Any tool purported to support communication must consider these points as requirements in selecting formatting and organizing information. This is the focus of our future work (Linot, Charoy, Dinet & Shalin, in review).

The solution is surely not simply to provide more information (Cooke et al, 2009). Misses occur in noisy, complex sociotechnical systems that although stochastic, rarely fail. Misses occur in the presence of potentially millions of mundane, correct decisions and responses. Changing decision criteria for the communication of information for possible future relevance must consider the resulting information overload in a system largely composed of correct behavior. Information overload is particularly critical when resources, especially response time, are limited. This is as relevant to crisis management as Deepwater Horizon, perhaps moreso.

Building shared awareness across the participants in distributed work, founded on information rather than data appears key. Lack of awareness concerning task dependencies and differences in organizational culture surely contribute to inconsistency in information sharing. However, in this case, pressure on subcontractor performance hardly encouraged the cross-sharing of doubt regarding the satisfactory completion of responsibilities. We can hope this property of Deepwater is not characteristic of crisis response.

The Deepwater data and our analysis are far from ideal in at least three respects. First, although they result from a real incident, they are post hoc accounts. Except for written records such as e-mail we cannot be certain that the language of recollection is the language actually used. Moreover, they result from investigative inquiry and though generally under oath, the data are not spontaneous. Finally, Deepwater is just a placeholder for a true crisis management event. The problem is not the absence of procedure and method in crisis response (FEMA, 2009). The problem is that the purpose of the system is different, to save lives and provide assistance to those in need. We cannot be sure that this context does not influence the nature of exchange, for example, by creating increased urgency by assembling teams even less familiar with each other than the teams in Deepwater or by magnifying the need for distributing an ever-evolving plan. The spatial modeling and reasoning in crisis management is more complex, as both the event and response likely involve the displacement of goods and services. Pre-existing instrumentation (fixed sensors) are less likely, as crisis generally occurs in unexpected, otherwise ordinary environments. In this view, relative to the complexity, diversity and necessarily ad-hoc response to crisis management, the communication lesson of Deepwater and the implications for the design of computational support is likely a best-case scenario.

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