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Materiality and emergence in environmental information systems

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Abstract

Information systems can be an integral part of environmental management practices enacted in the pursuit of environmental sustainability outcomes. We analyse the specific case of an environmental information system developed by a South Australian environmental regulator. The information system was intended to support efforts to sustain water quality by controlling the discharge of 'greywater' from vessels using South Australia's inland waters. We conceptualize the information system as the outcome of a continuing, though non-deterministic, trajectory of interacting material and human agencies, in the form of technology and routines. In our analysis, we trace how these basic building blocks of the system came to be, and how they shaped the emergent environmental information system in particular ways.

Keywords environmental information systems, emergence, imbrication.

1 Introduction

In this paper, we are concerned with how information systems support environmental sustainability initiatives and transformations (Elliot and Webster 2017). Environmental sustainability is an imperative of the highest global priority, requiring significant changes to behaviors and practices in business, government and society in order to address the deteriorating state of the natural environment – in particular in relation to air, water and land quality (Elliot and Webster 2017). Specifically, we focus on the ways that information systems materially 'scaffold' (Orlikowski 2006) environmental management practices. In doing so, we move from viewing an environmental information system as an isolated system, to an (integral) part of a larger whole that includes not only technical artifacts but also human actors and the sociomaterial practices that they engage in within broader organizational, social and political contexts.

In this view, 'green' information systems and their contribution to environmental sustainability (Hedman and Henningsson 2016) are treated as part of the technical and social arrangements that form environmental management in practice. Such arrangements often require improvisation (Orlikowski 1996) to resolve emerging tensions in practice (Braa et al. 2007). Analysing information systems in this way sees them as dynamic and emergent, as opposed to static and given (Orlikowski 1996). We seek to improve our understanding of how the technical and social components of environmental management, often conceptualized as technology and routines (Leonardi, 2011), come to be, and how they shape the ongoing development of environmental information systems.

Our key argument is that we cannot fully understand how and why an environmental information system is shaped in the way that it is, without understanding how emergent interactions between the technical and the social build upon the durable effects produced by sequences of prior interactions. In doing so, we seek to better understand the consequences of this process for the development of environmental information systems, as an important element of environmental sustainability practice. Thus, our research questions are *(1) how do environmental information systems emerge, and (2) how are they shaped in practice?*

To address these questions, we focus on an example of the environmental management of wastewater – liquid wastes and solid wastes mixed with water as the medium in which they are transported. Environmental stresses related to water scarcity and deteriorating water quality in various parts of the world have focused governmental and regulatory attention on wastewater as environmental problem. Many international initiatives, including the UN's Sustainable Development Goals consistently identify the risks and implications of wastewater for public health and the environment (e.g., United Nations 2018). In the domestic context, wastewater includes greywater as wastewater from household baths, showers, hand basins, washing machines, sinks or other kitchen appliances.

Our unit of analysis is an environmental information system developed by a South Australian regulator, the Environment Protection Authority (EPA), to manage greywater produced by vessels using the State's rivers and lakes. The key objective of this information system was to support the EPA's monitoring of compliance with environment protection legislation sustaining water quality in inland waters across South Australia. The 'vessel greywater management system' is composed of many social components including practices, norms, and institutions around vessel greywater discharge and management, but also technical components including digital artifacts, databases, standards, regulatory instruments, and greywater treatment systems.

We engage with the empirics of our case by using Leonardi's (2011) conception of imbrication, in which material and human agencies are progressively interlocked in a temporally emergent process. Our analysis of the South Australian vessel greywater management system offers a nuanced understanding of how a new environmental information system emerges as the product of intertwined social and technical elements and the roles of key actors in the processes of its production. This account demonstrates how the resultant system was successfully deployed in disciplining and regulating vessel greywater management practice. The paper proceeds with a discussion of the theoretical underpinning of the study, before outlining the case background and process of data collection and analysis. We then present our analysis and findings, followed by a concluding discussion and contribution.

2 Theoretical underpinning

The broader question concerning the nature of the relationship between the social and the technical has attracted much attention. Central to this research is whether material or human agency plays the primary role in explaining social and organizational change, for example resulting from information systems use. Nonhuman actors, including material artifacts and technology, can be said to have agency to the extent that they have the capacity to act independent of human intervention (Leonardi 2011). In contrast, human agency involves both action and intentionality (Leonardi 2013). Leonardi (2011) uses the metaphor of imbrication to conceptualize the process by which human and material agencies become progressively interlocked to create the routines and technologies that constitute sociomaterial practices of work and organization: "What is actually imbricated over time is human agency (which manifests itself in a group's goals and intentions) and material agency (the things a technology can do that are not entirely under the control of users)" (Leonardi 2013, p. 70).

Leonardi (2011) argues that routines and material artifacts, such as technologies, are flexible, changing over time as they are developed or used in practice in an emergent sequence of different imbrications of human and material agencies. Following Pentland and Feldman (2008, p. 249), routines are "generative systems that can produce patterns of action based on local judgement and improvisation by actors". Routines can be coded in material artifacts, such as rules, standards, formal standard operating procedures (SOP), and technology including software (Pentland and Feldman 2008). Material artifacts constitute the "formal, explicit, synthetic, selective, partial representations of routines" (D'Adderio 2011, p. 204). The distinction between material artifacts and routines is critical. Whilst, material artifacts are formalised representations that attempt to direct or prescribe performances that *should* occur, routines are *actual* performance expressions of the artifacts. However, routine performances are often only partial expression of an artifact because humans can interpret and use artifacts in different ways (e.g., modify or even neglect some or all of the artifact prescriptions), therefore resulting in routines that depart from the artifact designer's intentions (D'Adderio 2011).

A key benefit of conceptualising routines and material artifacts in this way is that they represent the empirically observable outcomes of particular interweavings of human and material agencies: "sometimes, human and material agencies interweave in ways that create or change routines; other times, they weave together in ways that produce or alter technologies" (Leonardi 2011, p. 151).

To theorize this process, Leonardi (2011) uses the concept of affordances – the different possibilities for action that a user perceives when they encounter a particular technology. As Leonardi (2011, p. 153) puts it, "people do not interact with an object prior to or without perceiving what the object is good for." There are two critical aspects to this assertion. First, while a technology's material properties may enable various functionalities, what a user perceives when confronting a technology is generally not the properties themselves but the kind of action that the technology in a given situation supports. Second, affordances are specific to the particular ways in which individuals perceive a technology in relation to their action-oriented goals and the particular contexts in which they are located. Thus, the opportunities for action associated with a particular technology are as diverse as the users' needs and goals. Equally, while some users may perceive that a technology affords them certain possibilities for action, others may perceive the same technology as constraining the possibility of achieving their goals (Leonardi 2011; Majchrzak and Markus 2013; Markus and Silver 2008).

Following Leonardi (2011), as people engage with an information system, perceived affordances and constraints influence how they choose to imbricate the human and material agencies associated with it: "perceptions of constraint lead people to change their technologies while perceptions of affordance lead people to change their routines" (p. 147). For instance, the perceived affordances of a technology may lead users to identify new goals that could be achieved through the material agency of the technology. However, achieving these new goals is likely to necessitate the exercise of their human agency to change the performance of existing routines or create new ones. Conversely, in confronting a technology that they perceive constrains their ability to achieve their current goal, users may redesign or reconfigure the material features of the technology so that it does new things – giving it new material agency (Leonardi 2011).

Viewed in this way, an information system is the outcome of an ongoing chain of imbrications, emphasizing the importance of analysing how this imbrication occurs, and how prior imbrications have shaped the routines and technologies that people use to organize and structure their actions.

Leonardi's (2011) conception of imbrication provides a useful analytical device with which to explore the emergence of environmental information systems. First, imbrication supports the epistemological understanding of interlocking or entangled human and material agencies as a way of making sense of a more complex reality (Iivari 2017). Second, imbrication conceptualizes the effects of this inter-agency entanglement as emergent system outcomes, namely, empirically observable and traceable routines and material artifacts including technologies (Leonardi, 2011). Third, imbrication suggests that at any point in time an environmental information system is an accumulation of durable residue from prior imbrication processes, and that future changes or extensions to the system will be conditioned (though not deterministically) by the existing system. Imbrication is thus a useful tool to improve our understanding of how environmental information systems are temporally emergent, the accumulation of prior intentions and actions that shape the system in certain ways, consistent with our research questions.

3 Contextual background

The EPA is an independent environmental regulator that administers South Australia's Environment Protection Act 1993. The EPA protects and restores land, air and water quality through the risk-based regulation of pollution and waste. One of the pressing challenges facing the EPA was addressing the environmental and human health risks and impacts associated with management of the River Murray (EPA 2012a). The river is the major source of domestic water supply and plays a key part in the State's tourism and recreation economy. However, water quality in the river had significantly declined due to high levels of water extraction, extended drought conditions, and pollution (DWLBC 2009). A significant pollution source is untreated greywater discharged from vessels using the river and its associated waterways. Greywater can contain pollutants such as soluble organic compounds, suspended solids, dissolved salts (nitrates and phosphates), and pathogenic micro-organisms (Eriksson et al. 2002). The River Murray is home to a thriving houseboat community, many with facilities such as washing machines, dishwashers, ensuite bathrooms and spa baths. With over 2,000 vessels on the River Murray, including some 300 commercial hire boats, it is estimated that up to 500 million litres of untreated greywater could be discharged into the river annually (EPA 2009). This practice is problematic with potential effects on aquatic ecosystem health, raw water supply and recreational use of waterways (EPA 2007a).

In response to the increasing environmental and public health risks associated with the discharge of vessel greywater, the EPA introduced a regime of greywater management policies, codes and guidelines that includes both mandatory requirements and best practice for greywater management. Underpinning the operation of this regime is an information system developed by the EPA to facilitate monitoring of vessel greywater management practice. The Vessel Management System (VMS) captures, processes, and reports data pertaining to compliance with greywater management regulations. While we focused our initial analysis on the VMS itself, it became apparent that in order to understand its current form and function we needed to also analyse how these had been conditioned by the accumulated effects of prior practices and processes involving both artifacts and actions. In particular, the role of a regulatory instrument called a Code of Practice that identifies high environmental risk activities, such as greywater discharge from vessels, and measures to manage them, became salient.

4 Methodology

The emergence of the VMS can be understood by examining the evolving interpretations of relevant organizations and actors as they interacted around the issue of vessel greywater management (Allen 2004). We captured these interpretations using primarily longitudinal qualitative empirical data (McLeod et al. 2011; Walsham 1993) from a ten-year period between 2004-13. Our data collection approach allowed us to obtain information from multiple sources and perspectives, producing a rich data set for analysis as well as ensuring additional validation through triangulation (McLeod et al. 2011).

Specifically, data were collected by reviewing relevant documents and archival records, including print and online publications of the EPA; internal EPA records such as unpublished reports, meeting minutes, consultation submissions, memos, formal correspondence and emails; newsletters, reports and white papers from other stakeholders in both government and the boating industry. This documentary evidence was supported by data collected from 31 interviews between the developers of the emerging vessel greywater management system and its stakeholders and users. These interviews took place between 2011-13 covered issues such as organizational interests related to vessel greywater management, organizational engagement and interaction processes, and drivers and inhibitors of VMS adoption.

Data collection and analysis proceeded hand-in-hand, with analysis undertaken as data became available and while collection continued, thus informing and guiding each other (Strauss and Corbin 1990). We analysed the rich and diverse qualitative data inductively consistent with our interpretive research approach, focusing on the content, context and process of information systems development (Walsham 1993). Employing intuitive sense-making and then extending into deeper inductive analysis, we identified patterns in the data. Themes potentially relevant to our research questions were then incrementally developed by condensing and conceptually grouping the identified patterns. By shifting frequently between specific elements and general themes, the analysis and findings were amended until a thorough understanding of the phenomena was developed.

The authenticity of the key constructs in this study has been addressed in three ways. First, where possible, we attempted triangulation across documentary evidence and the literature. Second, the interviewees provided different perspectives, which constitutes important triangulation of qualitative information by preventing biased opinions (Carson et al. 2001; Miles and Huberman 1994). Third, the chain of evidence tracing conclusions to collected data was maintained which enhanced construct authenticity of the research, thereby boosting its overall quality (Yin 2003).

5 Analysis and findings

Our analysis of the empirical evidence demonstrates how the technologies and routines comprising the emergent VMS were shaped by the imbrication of human and material agencies in the practices of its developers and users. Figure 1 summarizes the sequence of five imbrications we identified. The start and end points of our analysis are somewhat arbitrary as the 'chain of imbrications' constituting the VMS extends in either direction, with nominal beginnings reflecting the accumulation of earlier choices and future changes to the system equally likely (Leonardi 2011). We explain this sequence of imbrications in the following sections.

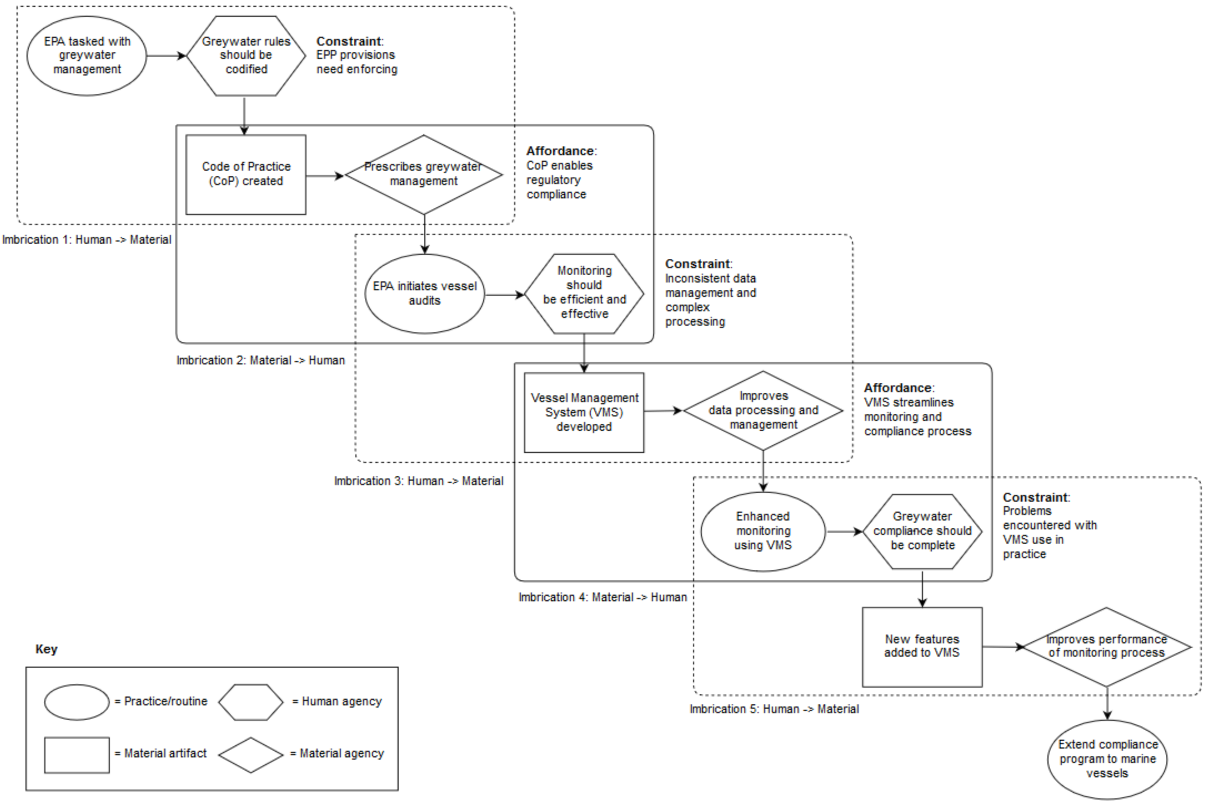

Figure 1. Evolution of the Vessel Management System

5.1 Imbrication 1 (Human → Material)

The State of South Australia's Environment Protection (Water Quality) Policy 2003 set water quality objectives, established general obligations to manage and control pollution, and encouraged better use of wastewater. It also specified additional obligations relating to wastewater discharge, including the operation of vessels on the State's rivers and lakes (EPA 2003). While the Policy acknowledged the need for vessel greywater management, the details of how this would be achieved would need to be developed by the EPA. Without establishing measurable outcomes and appropriate practices that users of vessels could follow, the EPA was constrained in its ability to ensure user compliance with the provisions of the EPP and prevent pollution from this source.

The EPA's goal of regulating vessel greywater management (human agency) could be achieved through the creation of a Code of Practice (CoP), a regulatory tool under South Australia's Environment Protection Act 1993 (material agency). A CoP examines the impact of a particular industry or activity and articulates practical and measurable outcomes for its regulation. It is a set of rules that details specific behaviours for complying with a particular Environment Protection Policy. The CoP describes both requirements, which 'must' be observed to avoid breaching the provisions of the Policy to which it is linked, and recommended practices, which 'should' be followed to achieve the desired outcomes. Compliance with its requirements can be enforced through the issuing of an Environmental Protection Order (EPO) (EPA 2019).

The process of developing the CoP involved extensive consultation and negotiation with stakeholders in the boating industry, local government and the community. Regulation of vessel greywater management would have a greater chance of being effective and accepted in practice if it was constructed collaboratively with those affected. The process needed to facilitate convergence on a set of rules for vessel greywater practice that could shape behaviours upholding environment sustainability. At the same time, it needed to offer opportunities for the industry and the wider public to identify issues with the emerging rules and for these to be resolved before the CoP came into effect.

A draft CoP was developed by the EPA and underwent several iterations in 2004, with revisions made after discussion and resolution of points raised by members of the EPA's External Advisory Group. This group included twenty-five representatives of key stakeholders of South Australia's waterways, both those directly or indirectly engaged in maritime activity and those affected by the threat to water quality (e.g., local business and vessel facilities, commercial and recreational vessel operators, state and local government, and boating industry associations) (EPA 2004).

In early 2005, the EPA released the draft COP for state-wide consultation and public comment. The aim of the consultation process was to engage stakeholders to review the draft CoP, both as a means of increasing its validity and as a source of constructive feedback for further revision. Engagement with the consultation process was promoted through a range of methods, including: the distribution of an information pack to over 2,000 stakeholders; a series of public consultation forums held at various locations across the State; and a comprehensive media campaign involving print advertisements, media releases and media contacts – resulting in multiple articles in South Australian newspapers and items on radio stations (EPA 2005; 2007b).

The rules that emerged from this process were eventually issued as the Code of Practice for Vessel and Facility Management (Marine and Inland Waters) in 2008 (EPA 2008a). Its greywater management requirements applied to all commercial and private vessels operating on inland waters, including the River Murray, but would be phased in over three years depending on the type of vessel (EPA 2008b). From the EPA viewpoint, the rules prescribed specific behaviours and the conditions under which they are acceptable (or not) and aligned these with the broader environmental protection goals. With respect to the management of greywater on vessels operating on inland waters, the resultant CoP defined two possible required outcomes – either preventing greywater from entering waterways or only discharging treated greywater (EPA 2008a).

Here we treat the CoP as a technical artifact, the product of conscious human agency and a concrete piece of the material culture surrounding environmental regulation in South Australia. Circulated, the CoP was capable of serving a specific material end in the practical accomplishment of water quality objectives (Verbeek and Vermaas 2009). The rules and recommended practices to govern vessel greywater management encapsulated in the CoP were specific and actionable. Adherence to them by vessel owners and operators would bring about the desired change to the existing greywater management practice and reduce the risk of greywater pollution. However, to be effective the rules had to be applied and observed consistently across South Australia. Their formulation as a CoP within the

State's environment protection regulatory framework produced a legal instrument, a technical device that the EPA could use to regulate greywater practice.

5.2 Imbrication 2 (Material → Human)

The new CoP afforded the EPA the possibility of regulating vessel greywater management and thus achieving its environment sustainability goals. It did this by providing specific and actionable greywater management requirements for vessel owners and operators, and the legal means for the EPA to enforce compliance with these provisions. Although the intention of the CoP was "to encourage best environmental management practices for the benefit of future generations" (EPA 2008a, p. 1), regulation through enforcement was eventually perceived as a necessary and effective course of action for the EPA: "Gaining compliance through regulation was really the only option for managing greywater discharges" (Interview #18).

Enforcing regulatory compliance implied the need to monitor the manner and extent to which vessel owners and operators were complying with the CoP. Data had to be collected via systematic monitoring, a new routine called an 'audit' by the EPA, to evidence when greywater management practice was compliant with the CoP and when it was not (e.g. EPA 2012b; 2015). The evidence could then be used by the EPA to monitor compliance and, if necessary, enforce the CoP by issuing EPOs to continued non-compliers. In this way, the material agency of the CoP became imbricated with the human agency of the EPA through the initiation of a compliance monitoring routine.

Audits involved EPA officers collecting compliance data during inspections of vessels in the field. Collected data included information about the owners or operators, the manner in which greywater was managed, and whether it was compliant with the CoP. Vessel owners and operators had the option to store greywater onboard for subsequent disposal at some 13 specific land-based pump out stations along the 650km South Australian part of the River Murray (DWLBC 2009). However, the stations were often difficult to access (e.g., due to the distance between stations, the number of vessels attempting to use them, or drought conditions affecting river levels). As a result, the CoP also included provisions that allowed vessels to discharge greywater into the river after it had been adequately treated onboard.

Vessels were typically deemed to be compliant with the CoP in relation to greywater management, when an EPA officer could establish that vessels had installed and were using an approved greywater treatment system that filtered greywater to the specifications prescribed in the CoP. 'Approved' greywater treatment systems were those that met a new standard (AS 4995) specifically developed by Standards Australia to provide an industry benchmark and accreditation system for the design, construction, installation and operation of onboard greywater treatment systems for vessels operated on inland waters (EPA 2008b).

The large number of vessels operating on South Australia's inland waters, the majority of them privately owned vessels, necessitated the use of random audits (EPA 2012b). Some audits targeted specific geographical areas, generally those with wharves, marinas and thus concentrations of vessels. Compliance data were collected manually in the field via paper forms and subsequently entered into spreadsheets at the EPA office. Image-based evidence documenting compliance complemented the vessel records in the spreadsheets.

Commercially operated vessels were handled differently, in collaboration with another South Australian regulator. Since all commercial vessels operating in South Australia were surveyed biennially by the Department of Transport, Energy, and Infrastructure (DTEI), it made sense for the DTEI to incorporate a check for greywater management compliance in their inspection and certification process (EPA 2009). The DTEI shared relevant data on the commercial vessels, including vessel identification and ownership information with the EPA. The data were received periodically from the DTEI in the form of a large spreadsheet. The information it provided was important for maintaining up-to-date records of addresses for correspondence (vessel owners have a responsibility with vessel registration to inform DTEI when their address changes, but have no such responsibility to the EPA) and for maintaining accurate records of vessels that go in and out of survey.

A major consequence of the new audit routine was the large amounts of data that it generated. In addition, the process of data capture in the field was inefficient and prone to errors. Subsequent processing of the data was complex and challenging. Typically, this entailed aggregation and disaggregation of data at different levels of granularity to fulfil the needs of different stakeholders. For example, stakeholders within the EPA and outside it, such as other government departments and industry associations, needed different types of reports. Additionally, the EPA tracked all correspondence to vessel owners and operators that formalized the findings of EPA officers during audits, and which required further action if the requirements of the CoP were breached. In summary, the EPA's audit practice involving manual records and spreadsheets presented many challenges, particularly in relation to data accuracy, manageability, complexity, compatibility, and consistency.

5.3 Imbrication 3 (Human → Material)

EPA staff began to perceive that their use of spreadsheets to store and manipulate audit data was constraining their ability to monitor vessel greywater management compliance efficiently and effectively (human agency): "Team members had identified that the current way the data was stored, using spreadsheets, was inefficient and time consuming" (Interview 22). In response, in the second half of 2010, a small team at the EPA commenced work on a requirements analysis and possible system functions for a new VMS, to be developed in-house using Oracle Database (EPA 2010a; 2010b). The data that were previously stored in spreadsheets would be restructured based on the Oracle database management requirements, which redefined granularity in the way the data were defined and stored in a relational database.

A key aspect of the new system was greater integration and consistency of the extensive data collected and maintained about individual vessels. These included ownership details, descriptions of on-board facilities capable of producing greywater, details of any onboard greywater treatment system (e.g., technical specifications, manufacturer information, model and serial number, installation and maintenance dates), and the presence and status of any issues or defects that might affect a vessel's compliance (EPA 2010b). As noted above, the vessel audits produced a large amount of associated image-based evidence, such as photographs, that could change over time. Consequently, a photo album feature was implemented in the VMS that enabled the building of image galleries for each vessel, with the capacity to store any number of photos necessary along with specific audit comments by EPA officers for each photo, including dates and other contextual information about objects featured in the photo.

Correspondence record management was another important aspect of the EPA's monitoring activities that influenced the development of the new VMS. Previously, EPA officers had undertaken mass mail-outs to vessel owners and operators asking for their plans on how they intend to become compliant with the CoP. These letters had generated a substantial subsequent correspondence that needed to be stored and differentiated in the database. The VMS needed to distinguish these owners as 'pending' compliance, until their vessel was inspected. Only then would a compliance letter be issued. Similarly, they needed to be excluded from any future correspondence sent to 'non-compliant' vessel owners. It was also desirable that the new system had the functionality to automatically generate certain standard letters at different points in the compliance process (EPA 2010a).

A major issue facing the VMS developers was how to capture and integrate the data relating to commercial vessels received from the DTEI. To facilitate more frequent sharing of data, a 'load module' was built for the VMS that could be used to update the VMS database based on changes in DTEI's records. The database structures used by the EPA and DTEI were significantly different, with the VMS holding more information on a vessel, so development of the load module required a large amount of coding and discussions between the two agencies. The role of the load module was to regularly input the DTEI data into a contained section of the VMS database and identify differences between the records, which EPA officers could then choose to update in the VMS schema. A change history allowed users to view or undo changes to maintain the data integrity of the EPA records.

As the EPA staff involved in compliance monitoring became familiar with the new VMS, they proposed improvements to the way data were processed or recognized other opportunities to exploit the potential of a database-driven solution. Consequently, the system developers were continually adjusting the functionality of the VMS in a process of incremental improvement. For example, while the various boating industry associations in South Australia did not actually own vessels, they were closely involved in the development of the CoP and the subsequent compliance monitoring regime. It was decided to include them in the VMS as a special class of 'owner', thereby leveraging the system's functionality to record EPA advice and handle the considerable correspondence the EPA had with these associations. In ways such as this, the EPA's goal of monitoring vessel greywater compliance effectively and efficiently (human agency) shaped the material development of the VMS.

5.4 Imbrication 4 (Material → Human)

During 2011, the EPA officers began using the VMS in their regular work so that the VMS became incorporated into the agency's monitoring and compliance routine (Spencer 2011). The VMS greatly facilitated ease of access to relevant vessel information, efficient records management, flexible and structured report generation, communication with vessel owners, and information exchange with other agencies. Its functionality allowed the EPA to maintain up-to-date information concerning a vessel's history and current compliance status. EPA officers could easily identify non-compliant vessel owners, send out warnings, and locate correspondence history concerning underlying causes and ensuing course of action taken. Because data were centralized, authorized EPA officers could access historical information about individual vessels including advice and recommendations provided at prior inspections, thus avoiding duplicate or contradictory actions. It was also useful as it constituted a complete record for each vessel that could potentially be used as evidence when EPOs were issued and legal action taken against CoP offenders.

The improved data processing and management offered by the VMS encouraged EPA staff involved in monitoring vessel greywater compliance to envisage ways that the system could enhance their practice. One example involved task management and the multitude of compliance dates that EPA officers needed to track. While the initial VMS would allow users to search and find all vessels that were nearing or past their compliance due date, "action items were developed to allow the system to have a task managing capacity" (Interview 8). New functionality was developed that allowed EPA officers to set dates for particular actions that needed to be completed or followed up on, triggering subsequent system-generated reminders on login when the relevant date arrived.

By early 2012, the requirement introduced by the CoP for onboard containment or treatment of greywater on all commercial and private vessels operating on inland waters was fully phased in. While some 60% of commercial vessels had become compliant, in order to achieve equity across the boating industry the EPA launched the next phase of the vessel greywater compliance program, involving further inspections, warning letters and, if necessary, EPOs (EPA 2012b). Arguably, the EPA interpreted the capability of the VMS to facilitate and streamline the monitoring of greywater management as affording them the ability to "ramp up" (ABC 2012) their efforts to ensure complete compliance with the CoP. The material agency of the VMS was imbricated with the agency of the EPA officers through the enhancement of their activities around compliance monitoring.

5.5 Imbrication 5 (Human → Material)

To achieve the goal of ensuring as complete as possible compliance with the greywater management regulations as set out in the CoP, EPA staff increased their activities around vessel monitoring. In doing so, they encountered several problems affecting the efficacy of their monitoring work. These constraints in the greywater monitoring practice prompted the EPA to consider the development of refinements in the VMS and the manner in which it was used in attempts to overcome them.

One issue revolved around data verification in the field. The VMS was located inside the EPA's intranet and could not be accessed externally, for example by EPA officers conducting a vessel audit. This meant that when talking with vessel operators and owners about greywater management and their vessel's compliance status, officers did not have real-time access to up-to-date information held in the VMS. During an audit, some vessels owners would make claims to EPA officers in relation to specific compliance issues. Without access to the VMS, officers were unable to verify these claims or provide appropriate advice.

The current material configuration of the VMS was constraining the ability of EPA officers to operate efficiently and effectively in the field. New functionality was developed that enabled a version of the VMS database to be copied before an audit onto a handheld computer specifically designed to withstand rough handling in field conditions. This arrangement provided the EPA officers on vessel audits with the ability to access up-to-date records while working at a distance from their office. The human agency of the EPA officers was imbricated with the material agency of the mobile device that extended the reach of the VMS.

Over time, use of the VMS was successful in achieving a high level of compliance for vessels operating South Australia's inland waters (Brennan 2013). Data retrieved from the VMS in early 2014 indicated that 82% of commercial vessels and 77% of recreational vessels on inland waters were greywater compliant with the CoP, with the most common reasons for non-compliance being significant financial constraints, absentee or new owners and extreme climate events (EPA 2013). As the EPA realized that the heterogeneous arrangements based around the CoP and VMS could be effectively used to achieve a high compliance level, they turned their attention to vessels operating in the State's offshore waters. This would involve EPA staff extending their monitoring and compliance routine to a new environment: "Once we start to get on top of the vessels on inland waters we will need to turn our focus to marine waters" (Internal EPA email 18 April 2011).

6 Concluding discussion

Our analysis of the South Australian vessel greywater management system demonstrates how its emergence involved progressively developing and co-implicated routines and technologies. Each technical artifact and its (re)configuration contributed to reduce the instability brought forth by perceived constraints in the evolving system. They achieved this by offering new forms of material agency, and therefore greater scope for affordances to be perceived that could help achieve (human) goals. In turn, routines were created or changed through the exercise of human agency to better perform vessel greywater management in practice. This finding is important because it explains not only how the VMS was shaped, but also how the system itself pushed back, shaping greywater management practice.

The case of the environmental information system analysed here is consistent with Leonardi's (2011) articulation of how interweaving human and material agencies lead to an ongoing sequence of changes as routines and technologies are developed and used in practice. Of course, if human and material agencies are to become imbricated, "someone has to arrange them in a particular way" (Leonardi 2011, p. 164). In our analysis, this role was predominantly carried out by an environmental regulator, the EPA. While the actions of other actors were often significant, for example in setting high-level aims, highlighting concerns, or creating practical issues that needed to be overcome, it is clear that the EPA played a leading role in orchestrating the emerging VMS and the approach to vessel greywater management it was embedded in. The EPA was effective in identifying both possibilities and limitations in the emerging system as it continuously updated its short-term goals in alignment with its mission to achieve environmental sustainability in the longer term. Without this, the sequence of imbrications observed in our case would not have been possible. The EPA had the power and legitimacy to both speak for and act to protect the environment through its institutional position in South Australia's environmental legislative framework. It also had the resources to fund development activity that ultimately aligned the interests of diverse stakeholders and produced the technical artifacts that formed the VMS.

Our account of the emergence of the VMS also demonstrates how choices and decisions that the EPA made at particular junctures were influenced by the shape of the system produced in earlier imbrications. An environmental information system has a biography and a history. Past imbrications of human and material agencies produce the perceptions of affordance and constraint that create a space in which people are motivated to act, to make new imbrications that result in a continuing, but non-deterministic, trajectory of changes in routines and technologies (Leonardi 2011).

Finally, our analysis of the emergence of the VMS demonstrates the constitutive role of both human and material agencies in its development. Using an imbrication lens necessarily acknowledges the active role played by technology and technical artifacts in the development and operation of environmental information systems. The concept of imbricating human and material agencies emphasizes the empirical operationalization of routines and technologies as observable figurations (Leonardi 2011). Used in this way, it can be a helpful analytical device for unpacking and tracing the process by which environmental information systems are constituted and evolve over time.

From a practical viewpoint, this study illustrates how information systems development in environmental management is a complex process. It points to the need for an awareness by agencies and actors involved that perceived affordances and constraints can trigger particular interactions between human agency and the material, both in terms of the natural environment and the technical artifacts produced by those seeking to manage it. This also opens up the possibility of identifying opportunities for influencing the outcome of these imbrications, and thus to possibly to shift the trajectory of future system development. While our analysis is based on a single case of an environmental information system development, and our findings are particular to the trajectory of this specific system, they offer insights that can inform both the development and analysis of environmental information systems in other settings. Our study also offers a useful empirical validation of the efficacy of imbrication as an analytical device for making sense of the temporally emergent, heterogeneous assemblages that comprise information systems.

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