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WHEN FLEXIBLE ROUTINES MEET FLEXIBLE TECHNOLOGIES: AFFORDANCE, CONSTRAINT, AND THE IMBRICATION OF HUMAN AND MATERIAL AGENCIES[1]

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Employees in many contemporary organizations work with flexible routines and flexible technologies. When those employees find that they are unable to achieve their goals in the current environment, how do they decide whether they should change the composition of their routines or the materiality of the technologies with which they work? The perspective advanced in this paper suggests that the answer to this question depends on how human and material agencies—the basic building blocks common to both routines and technologies—are imbricated. Imbrication of human and material agencies creates infrastructure in the form of routines and technologies that people use to carry out their work. Routine or technological infrastructure used at any given moment is the result of previous imbrications of human and material agencies. People draw on this infrastructure to construct a perception that a technology either constrains their ability to achieve their goals, or that the technology affords the possibility of achieving new goals. The case of a computer simulation technology for automotive design used to illustrate this framework suggests that perceptions of constraint lead people to change their technologies while perceptions of affordance lead people to change their routines. This imbrication metaphor is used to suggest how a human agency approach to technology can usefully incorporate notions of material agency into its explanations of organizational change.

Keywords: Affordances, agency, materiality, routines, organizational change, technological change, perception, imbrication

Introduction

Today, few people complete their work without the use of advanced information technologies. Employees in knowledge-intensive firms are inundated with information technologies, from productivity tools, to simulation software, to decision systems. The use of information technologies outside of knowledge-intensive occupations is also growing. Professionals such as plumbers use digital imaging and recording devices to find clogs in sewer lines; excavators use geographical positioning systems to accurately identify the correct depth for foundation footings; city planners use 3D animation software to model traffic patterns and identify bottlenecks before choosing the locations of roadways and pedestrian paths.

The recognition that advanced software-based information technologies (hereafter, just technologies) are permeating every aspect of people's work has prompted researchers to question the extent to which these technologies determine our practices and, in so doing, dominate our lives. A burgeoning line of research adopting a human agency perspective has provided a fairly optimistic answer to this question. *Human agency* is typically defined as the ability to form and realize

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one's goals (Emirbayer and Mische 1998; Giddens 1984). For example, a person may ask a question because she wants a response, or use a word processing program because she wants to produce a report. Both are empirically observable examples of enacted human agency. A human agency perspective suggests that people's work is not determined by the technologies they employ. As Orlikowski (2000, p. 412) notes, people "have the option, at any moment and within existing conditions and materials, to 'choose to do otherwise' with the technology at hand." Studies show that even in the face of the most apparently constraining technologies, human agents can exercise their discretion to shape the effects those technologies have on their work (Azad and King 2008; Boudreau and Robey 2005; Vaast and Walsham 2005).

Within this approach, scholars are beginning to recognize that people often enact their human agency in response to technology's material agency (Jones 1998; Pickering 2001; Volkoff et al. 2007). *Material agency* is defined as the capacity for nonhuman entities to act on their own, apart from human intervention. As nonhuman entities, technologies exercise agency through their "performativity" (Barad 2003; Pickering 1995); in other words, through the things they do that users cannot completely or directly control. For example, a compiler translates text from a source computer language into a target language without input from its user and a finite element solver calculates nodal displacements in a mathematical model and renders the results of this analysis into a three-dimensional animation without human intervention.

Most authors have treated human and material agencies as having a unidirectional relationship. People who have goals and the capacity to achieve them (human agency) confront a technology that does specific things that are not completely in their control (material agency). In the enactment of their goals, then, people must contend with the material agency of the technology. That is, people must figure out how to maneuver around it. Studies show that rejecting the technology (Constantinides and Barrett 2005; Lapointe and Rivard 2005; Markus 2004) or using its features for purposes other than designers or implementers intended (Boudreau and Robey 2005; DeSanctis and Poole 1994; Schultze and Boland 2000), are two common strategies by which such maneuvering occurs. This unidirectional characterization of the relationship between them casts people as dynamic (they can form new goals and imagine new methods to achieve them) and technologies as static (the technology has a fixed set of material parameters that do not change across contexts or groups of users).

To achieve their goals in the face of constraints imposed by an obdurate piece of hardware or software, people must change some other aspect of their environment. Research suggests that organizational routines—sequential patterns of social action (Pentland and Rueter 1994)—are the aspects of work most often changed. For example, Poole and DeSanctis (1992) showed that when users of a GDSS experienced constraints on their ability to reach group consensus, they changed decision-making routines so they could come to agreement. Zack and McKenney (1995) showed that when e-mail constrained newspaper editors' ability to follow the norms of their functional structure, they changed their consultation routines so they could preserve occupational roles and responsibilities. Leonardi (2007) showed that when a knowledge management technology constrained computer technicians' ability to learn from coworkers, they changed their documentation routines. In each case, people had goals that the technology made possible, but difficult to achieve, so they exercised their human agency to change their routines so they could still achieve their goals in spite of the constraints they perceived material agency created for them. Human agency is realized by both using the capabilities provided by technology and resisting the limitations those capabilities impose. In none of these cases did the authors document users physically changing the technology directly to achieve their goal by writing a script, developing a new module, or asking developers to modify the functionality of an application. Indeed, most studies depict the relationship between technology and organizing as a process in which human agency reacts to material agency by producing changes in routines (sometimes even by using the technology's existing material agency in unanticipated ways), but leaving the technology's features intact (e.g., Barley 1990; Chu and Robey 2008; Schultze and Orlikowski 2004).

The resultant theoretical image of flexible routines and inflexible technologies that current research proposes does not adequately represent the empirical reality of many contemporary workplaces. Today, workers have many opportunities to make material changes to the technologies with which they work. A good deal of research within the field of information systems has shown new technologies to be quite flexible. From data repositories (Alavi and Leidner 2001) to networked collaboration tools (Majchrzak et al. 2000) to computer simulation software (Dodgson et al. 2007), technologies are increasingly designed to be customizable and adaptable to the needs of developers and users. Although not all people have the skills to change the features of a technology themselves, research shows an increasing number of individuals employed within organizations as in-house developers, IT staff, or on-site consultants that do have them (Pollock et al. 2007; Tabrizi 2005). Thus, a flexible technology is not necessarily flexible because of any inherent properties of the artifact. Rather, it is flexible because it is embedded in a context where people can have it modified to fit their needs in relatively short order. In many modern organizations it may be as easy for people to change the material makeup of a technology, and hence its material agency, as it is for them to change existing routines.

In this paper, the relationship between human and material agencies in contexts where people work with flexible routines and flexible technologies is explored. The specific argument is that studying contexts in which people can choose whether they will change routines or technologies puts into relief that human and material agencies are the shared building blocks of routines and technologies. This suggests that, although they interact directly with one another, human and material agencies are distinct phenomena. By themselves, neither human nor material agencies are empirically important. But when they become imbricated—interlocked in particular sequences—they together produce, sustain, or change either routines or technologies. To explain what changes when depends on an understanding of the sequence of imbrications between human and material agencies. In what follows, this perspective is developed theoretically and illustrated empirically with data from a longitudinal study of the organizing process around a new simulation technology in a large automotive engineering firm.

Agencies, Affordances, and Imbrications

Differences between Human and Material Agencies

Over the past two decades, proponents of a human agency approach have adopted several theoretical perspectives from the social sciences that foreground the role that humans play in shaping their own outcomes. Among these perspectives, structuration theory has been most often employed (see Jones and Karsten 2008; Poole and DeSanctis 2004) to show that people draw on norms and communication processes to shape their interaction with a technology. Because people approach technologies from varying vantage points, they often enact distinct technologies-in-practice (i.e., ways of using the technology, Orlikowski 2000). IS-specific variants of structuration theory foreground people's interpretations, which are guided by their goals, in shaping their interactions with a technology (DeSanctis and Poole 1994; Orlikowski 1992; Walsham 2002). Building on the groundwork laid by structurational treatments of technology, Boudreau and Robey (2005, pp. 3-4) note that "a human agency position suggests that humans are relatively free to enact technologies in multiple ways… .Technology is implicated in social change at the discretion of human agents."

Agency is, of course, given a central role in structuration theory. Giddens (1984) defines agency as the "capacity for action." At first glance it may seem that such a definition extends agency to humans and technologies alike. But Giddens makes an important qualification. He suggests that all action involves motivation, rationalization, and reflexive monitoring (p. 5). These cognitive processes are linked to human intention.[2] People have goals that motivate them. They can rationalize their goals as acceptable given a set of circumstances and they can continuously monitor their environment to determine whether or not the goal is being achieved. For this reason, Giddens notes that "agency concerns events of which an *individual* is the perpetrator" (p. 9). Given Giddens' explicit bestowal of agency upon humans, Rose et al. (2005) observe that the idea that technologies could be seen to have material agency is problematic within structuration theory because it "sees agency as a uniquely human property" (p. 133) and "technology as having no agency of its own" (p. 137). Orlikowski (2005, p. 184) concurs that "structurational treatments…privilege human agency and (inappropriately) discount technological agency" and has suggested that structuration theory may be unable to fully account for the fluid and flexible interchange between the material agency of technologies and the human agency of those who produce and use them because "structurational perspectives reflect the humanist tradition of making the human subject the center of the action."[3]

Although Giddens limits agency to being a property held by humans, his theory of structuration does respect the role that materiality plays as a prop for human action. He argues (in Giddens and Pierson 1998, p. 821), for example, that

> [people] do what they do in lots of different contexts, including physical contexts, which are highly strongly relevant to the possibilities and constraints facing any individual or group....We live in a physi-

[2]Giddens suggests that not all actions achieve one's goals for them. Many actions produce outcomes that were unanticipated, meaning that they are different than the outcomes people envisioned when forming their goals. As we shall see, this conception is compatible with the theory of imbrication developed in this paper. As argued below, imbrications of human and material agencies produce technologies or routines, which (intended or not) may often guide future action.

[3]For a more extended review of authors who claim that structuration theory overlooks or denies the material agency of technologies, see Markus and Silver (2008, pp. 615-616).

> cal world that has causal effects in the sense that you just can't walk straight through a wall.

Giddens' view of agency is developed and deployed in his specific discussions about social structure, which he argues "doesn't have the same kind of existence as a physical structure, nor do its causal effects" (Giddens and Pierson 1998, p. 821). That technologies are not within Giddens' sphere of interest, and hence not treated directly in a theory of structuration, does not mean that they do not exert some form of influence on the social. Their influence is of a different order to that of the social agency/structure relationship with which Giddens is concerned in his work. The difficulties IS scholars have with structuration theory may well arise because Giddens does not attempt to address their concerns, not because his theory is necessarily inimical to them.

Recognizing that a structurational approach provides a useful framework for exploring how people actively structure their environments, but that it lacks a specific capacity for theorizing the role of technological artifacts, some proponents of the human agency approach have looked to augment the structurational approach with the concept of material agency, which they borrow from actor–network theory. The conceptualization of nonhuman entities, such as technologies, doing things that cannot be reduced to human intentionality is a core tenet of actor–network theory. Yet owing to their roots in structurational approaches, proponents of a human agency approach have been uncertain about how to respond to the provocative claim in actor–network theory that material agency is equivalent, in semiotic terms, to the agency of humans (Callon 1991; Latour 1992). Because of this semiotic equivalence, actor–network theorists argue that neither human nor material agency should be given priority in the explanation of people's construction of outcomes. Rather, each contributes equally to shaping the other, and people and technologies are recursively implicated as they use each other to build associations (Latour 2005). On the one hand, proponents of the human agency perspective very much resonate with the assertion in actor-network theory that technologies have material properties that confront humans as external objects. Authors discuss how human agents need to grapple with the material agency of technology as they work to achieve their goals (Boudreau and Robey 2005; Walsham 2005). On the other hand, proponents of the human agency approach are uncomfortable with actor–network theorists' belief in the equivalence and interchangeability of human and material agency (Chae and Poole 2005; Leonardi and Barley 2008).

Taylor and colleagues (2001, p. 71) provide a useful language for reconciling the notions of human and material agency in a way that thoughtfully builds at the intersection of structuration and actor–network approaches. They argue that although human and material agencies both influence people's actions, their influence is disproportionate because human agency always has a "head status" while material agency has a "complement status":

> It is not that Agent$_1$ (some human) had purposes and Agent$_2$ (tool) does not (they both incorporate purposes, and both have a history that is grounded in previous mediations), but that we generally attribute head status to the human agent and complement status to the tool. In this way, the human subjectivity is given recognition even as the subject's agency (the capability of acting) is constituted objectively, as an actor in mediated communication with others. In this sense, Giddens is right: Intentionality is a product of reflexive interpretation. However, he fails to see the implications of his own principle. That to which we accord intentionality becomes, ipso facto, an agent—individual or not.

By treating the relationship between human and material agencies in this way, Taylor et al. are able to successfully incorporate into the human agency approach the recognition that technologies have a material agency that transcends changes in context while still giving primacy to the people who design and use them.[4] The ability to do this rests on the use of a metaphor of *imbrication*.

Imbrication of Human and Material Agencies

Authors such as Taylor (2001), Ciborra (2006), and Sassen (2006) have recently begun to characterize the interweaving of human and material agencies as a process of *imbrication*. To imbricate means to arrange distinct elements in overlapping patterns so that they function interdependently. The verb *imbricate* is derived from names of roof tiles used in ancient Roman and Greek architecture. The tegula and imbrex were interlocking tiles used to waterproof a roof. The tegula was a plain flat tile laid on the roof and the imbrex was a semi-cylindrical tile laid over the joints between the tegulae.

[4]This observation is similar to Collins and Kusch's (1998) claim that researchers (and lay observers) often attribute agency to machines when the "vantage point is low in the action tree" (p. 124). In other words, the analyst looks only at the technology without recognizing that it is embedded in a web of human agency. Collins and Kusch don't discount that technologies can act on their own, but they caution researchers to keep in mind, like Taylor and his colleagues do, that it is always humans that are configuring material agency and deciding how it will become interwoven with their goals.

The interlocking pattern of tegulae and imbrices divided the roof into an equal number of channels. The imagery of tiling suggests that different types of tiles are arranged in an interlocking sequence that produces a visible pattern. A roof could not be composed solely of tegulae nor of imbrices—the differences between the tiles in terms of shape, weight, and position prove essential for providing the conditions for interdependence that form a solid structure. Human and material agencies, though both capabilities for action, differ phenomenologically with respect to intention. Thus, like the tegula and the imbrex, they have distinct contours yet they form an integrated structure through their imbrication.[5] Taylor and his colleagues (2007, p. 399) suggest that this integrated structure is an organizational structure: "Applied to organizational analysis we consider [imbrication] to be the way that interagency relationships are interweaved to form… infrastructure."

The argument in this article is that the routines and technologies are the infrastructure that the imbrication of human and material agencies produce. Put another way, if we were to examine routines and technologies under a microscope, we would find that each is made up of the same basic building blocks: human and material agencies.[6] Although we may make the ontological claim that routines and technologies are indistinguishable phenomena because they are both constituted by human and material agencies, we must be mindful that the ways in which those agencies are weaved together produce empirically distinct figurations.[7] Latour (2005, p. 53) defines *figuration* as the process by which agencies take on observable properties:

> If you mention an agency you have to provide the account of its action, and to do so you need to make more or less explicit…its observable traces.…If agency is one thing, its figuration is another. What is doing the acting is always provided in the account with some flesh and features that make them have some form or shape.

Thus, 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.

The metaphor of imbrication is in several ways useful for explaining the interweaving of human and material agencies. First, imbrication suggests that human and material agencies are effectual at producing outcomes (e.g., routines or technologies) only when they are joined together, but that their interdependence does not belie their distinct characters. As Sassen (2006, p. 345) suggests,

> I use the term imbrication to capture the simultaneous interdependence and specificity of each the digital and the nondigital. They work on each other but they do not produce hybridity. Each maintains its distinct irreducible character.

Thus, the notion of imbrication allows for maintaining the distinction between human and material agencies with respect to intentionality while still recognizing their synergistic interaction. The metaphor of imbrication is distinct from Latour's (1993, 1999) notion of the *hybridicity* between the human and the material. Latour argues that human and material agencies are indistinguishable (they are hybrids) such that action has no point of origin. In other words, either people or technologies can begin changes in sequences of action.[8] By keeping the distinction between human and material agencies, the imbrication metaphor asserts a slightly different relationship: people have agency and technologies have agency, but ultimately, people decide how they will respond to a technology. As Cooren (2004, p. 377) suggests, "To say that nonhmans *do things* does not mean that human contributions are passed over…humans can appropriate what nonhumans do."

Second, because the metaphor of imbrication sensitizes us to the production of durable patterns, it reminds us that all interactions between human and material agencies produce an organizational residue. When human and material agencies

[5]Clearly, using the imagery of imbrices and tegulae has its problems. Both tiles are made of "material" in the sense that they are physical creations of clay. The struggle to find a suitable image with which to describe the imbrication of human and material agencies points to the conceptual difficulty of integrating these phenomena. Thus, the analogy is meant to be illustrative rather than to be read literally.

[6]This view coincides with the recent tendency to call into question the distinction between routines and technologies. This tendency is based on ontological claims such as (1) routines are patterns of social action that are often mediated by technology (Pentland and Feldman 2007) and (2) a technology's material form is shaped to a significant degree by the routines of product development (Dougherty 1992; Garud and Rappa 1994), and a technology can only have effects on the way people work if it becomes a technology-in-practice; that is, if it is incorporated in people's existing work routines (Orlikowski 2000; Vaast and Walsham 2005).

[7]This is akin to saying (as chemists do) that our theories of physical chemistry should treat diamond and graphite as equivalent because they are both made of carbon, but empirically we must distinguish between them because they have different crystal structures by virtue of the ways in which the carbon atoms have interlocked.

[8]For a more detailed discussion of this point, see Latour's (1994, pp. 30-33) example of the relationship between a person and a gun.

imbricate to produce routines or technologies, those figurations have staying power. Routines persist absent their creators (Cyert and March 1963), as do technologies (Mackay and Gillespie 1992). As the people within the organization continue to use routines and technologies in practice they become, in Star and Ruhleder's (1996) terms, *infrastructure*. That is, they provide the context and the means for organizing to happen, but they are taken-for-granted as natural relations. The imbrications that produce routines and technologies become "black-boxed" such that we no longer actively question why we have certain routines or technologies or what they are good for. As organizational infrastructure, Taylor et al. (2001) suggest that imbrications are only ever, to use Heidegger's (1959) distinction, "ready-to-hand" (*zuhanden*) as opposed to "present-at-hand" (*vorhanden*). That is, the capabilities that human and material agencies create as they interlock with one another become proceduralized and forgotten over time. As long as human and material agencies are imbricated in ways that allow people to get their work done, the structures they create are transparent and always ready-to-hand as opposed to actively and reflexively drawn upon in every day action (present-at-hand). Thus the products of prior imbrications (e.g., a routine or a technology) lay the groundwork for continued organizing in that they provide the routines and technologies that people can use to structure their actions. Because the interweaving of human and material agencies produces routines and technologies that are regularly used by organizational members, we can say that past human–material imbrications influence how human and material agencies will be imbricated in the here-and-now.

With this recognition, the imbrication metaphor provides a third benefit to theory in that it enables a way to appreciate accumulation over time without resorting to deterministic language. As several scholars have argued, in order to bridge the gap between the extreme poles of determinism and voluntarism, researchers must better explain how the accumulation of past changes bears on present changes (Leonardi and Barley 2008; Schultze and Boland 2000). Imbrication implies accumulation in the sense that the overlap of human and material agencies is not replicated in the same way over time and does not necessarily have inertial tendencies, but that the way imbrication occurs at Time 1 will influence the way it occurs at Time 2. As Ciborra (2006, p. 1345) explains,

> Imbrication is…more subtle than a mere overlapping or mutual reinforcement….It is more "active" than that. Its sense possibly can be best captured by the technical meaning of the term imbrication in the (French version) of the Unix operating system: *imbrication* is the relationship between two lines of code, or instructions, where one has as its argument (on which it acts) not just as the result of the other, but also the ensuing *execution of that result*.

Imbrications at one point in time create the possibility for (and set certain restrictions on) future imbrications, although in a nondeterministic way. By recognizing that accumulated nature of past human–material imbrications, an imbrication perspective must provide a language to explain how activities in the past condition (as opposed to cause) future human–material sequencing.

Construction of Affordances and Constraints as Catalysts for Imbrication

The preceding discussion uses the metaphor of imbrication as a way of recognizing that human and material agencies are distinct phenomena but that they are fundamentally interdependent; that past imbrications accumulate to help explain, although certainly not predict, how human and material agencies will become conjoined in the future; and that people actively work, within the framework established by previous imbrications, to reconcile their goals (human agency) with the things that a technology can or cannot do (material agency).

As outlined above, human and material agencies are the basic common building blocks of routines and technologies. To the extent that routines and technologies are both flexible; people can change or have them changed as they are developing or using them. Changes in routines or technologies, then, require new imbrications of human and material agencies. Yet if a person has the option of changing a routine or changing a technology, how does she decide which one to change? To answer this question, we must consider the differential ways in which human and material agencies can become imbricated. To do so, we turn to a theory of affordances, which provides a vocabulary useful for theorizing the imbrication of human and material agencies.

In an effort to explain how animals perceive their environments, James Gibson (1986) a perceptual psychologist, suggested that surfaces and objects offered certain affordances for action:

> If a terrestrial surface is nearly horizontal…nearly flat…sufficiently extended…and if its substance is rigid…then the surface *affords* support….It is stand-on-able, permitting an upright posture for quadrupeds and bipeds….Note that the four properties listed—horizontal, flat, extended, and rigid—would be *physical* properties of a surface if they were mea-

> sured with scales and standard units used in physics. As an affordance of support for a species of animal, however, they have to be measured *relative to the animal*. They are unique for that animal. They are not just abstract physical properties (p. 127).

In Gibson's formulation, people do not interact with an object prior to or without perceiving what the object is good for. As he suggests, the physical (or material) properties of an artifact exist apart from the people who use them, but they are infused with meaning "relative to the posture and behavior of the animal being considered" (pp. 127-128). The concept of affordance is useful in explaining why human and material agencies become imbricated: Technologies have material properties, but those material properties afford different possibilities for action based on the contexts in which they are used. Although the material properties of a technology are common to each person who encounters them, the affordances of that artifact are not. Affordances are unique to the particular ways in which an actor perceives materiality. To this end, Gibson offers a perceptual explanation of the relationship between materiality and affordances:

> The psychologists assume that objects are composed of their qualities…color, texture, composition, size shape and features of shape, mass, elasticity, rigidity, and mobility….But I now suggest that what we perceive when we look at objects are their affordances, not their qualities. We can discriminate the dimensions of difference if required to do so in an experiment, but what the object affords us is what we normally pay attention to (p. 134).

Because materiality can provide multiple affordances, it is possible that one artifact can produce multiple outcomes.

Gibson's work has been most notably applied to discussions of technology by Norman (1990, 1999), who argues that good designers purposefully build affordances into a technology to suggest how its features should be used. Norman (1990) seems to suggest that affordances are intrinsic properties of artifacts and that the role of design is to make affordances easily perceptible to would-be users:

> Affordances provide strong clues for the use of their materials. Plates are for pushing. Knobs are for turning. Slots are for inserting things into. Balls are for throwing or bouncing. When affordances are taken advantage of, the user knows what to do just by looking: no picture, label, or instruction is required (p. 9).

For Norman, affordances are "designed-in" properties of artifacts. The goal of an affordance is to signal to the user what the technology can do and how it is to do that thing. To do this, designers must make affordances easy to perceive: "The designer cares more about what actions the user perceives to be possible than what is true" (Norman 1999, p. 39). Users are important to Norman inasmuch as they can identify a technology's affordances; however, they play little role in creating affordances. Instead, affordances are created strategically (if she is good at her job) by the designer. In this formulation, Norman's argument is different than Gibson's in that he claims affordances do not change across different contexts of use; rather, they are always there waiting to be perceived.

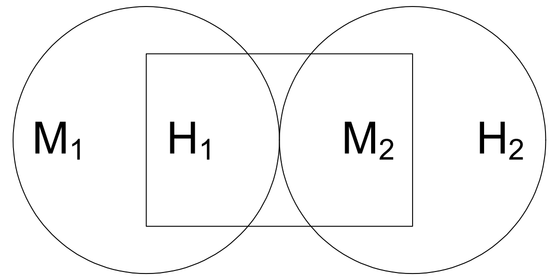
Hutchby (2001) seeks a middle ground between these prior conceptualizations by emphasizing the relational character of affordances. In his view, affordances are not exclusively properties of people or of artifacts; they are constituted in relationships between people and the materiality of the things with which they come in contact. In this formulation, materiality exists independent of people, but affordances and constraints do not. Because people come to materiality with diverse goals, they perceive a technology as affording distinct possibilities for action. For Hutchby, the affordances of an artifact can change across different contexts even though its materiality does not. Similarly, people may perceive that a technology offers no affordances for action, perceiving instead that it constraints their ability to carry out their goals.

Markus and Silver (2008, p. 620) suggest that

> in terms of the relational concept of affordances… properties of objects are seen as necessary but not sufficient conditions [for changes in action]…. Because action is goal-oriented, it is neither required nor appropriate to describe objects and affordances in a reductionist fashion.

To emphasize that affordances arise when a person interprets a technology through his or her goals for action, Markus and Silver define affordances as "the possibilities for goal-oriented action afforded to specific user groups by technical objects" (p. 622). Because affordances are relational—existing between people and an artifact's materiality—artifacts can be used in myriad ways and have multiple effects on the organization of work (Fayard and Weeks 2007; Zamutto et al. 2007).

According to the relational view, we might argue that affordances and constraints are constructed in the space between human and material agencies. People's goals are formulated,



Note: Circles represent figuration of agencies as routines, square represents figuration of agencies as technology. Routines and technologies are constituted by different imbrications of the same basic agencies.

Figure 1. Imbrication of Human and Material Agencies Produces Routines and Technologies

to an important degree, by their perceptions of what a routine or a technology can or cannot do, just as those perceptions are shaped by people's goals. For this reason, the argument is that as people attempt to reconcile their own goals with the materiality of a technology, they actively construct perceptual affordances and constraints. Depending on whether they perceive that a technology affords or constrains their goals, they make choices about how they will imbricate human and material agencies. Acting on the perceived affordances of a technology can then lead users to realize new intentions that could be achieved through these material features. The different ways in which human and material agencies are imbricated results in distinct outputs—either a new routine, or a new technology.

To illustrate this point, consider the following example, which is extremely basic for descriptive purposes. Coordinators in a not-for-profit community organization have recently begun to disseminate reports to community members that summarize the organization's service activities. This news dissemination routine is heavily reliant on the use of a word processing technology that coordinators can use to create the summary. The word processing technology is configured to act in particular ways (material agency) and the capabilities that it provides are partially what led the coordinators to envision creating the newsletter in the first place. The news dissemination routine is enabled by the functionality of the word processing technology (material agency) that allows coordinators to create a summary document and the goal of disseminating information to community members (human agency), which was partially formulated by the acquisition of the technology. In Figure 1, this routine is depicted as a circle made up of material agency (M_1) and human agency (H_1).

As the coordinators use the word processing technology and reflect on its output, they decide that they would like to be able to turn their boring text-document into a visually appealing, well-formatted newsletter. They attempt to use their current word processing technology to do so, but they discover no easy capabilities that will allow them to format the text in unique ways and to draw diagrams. In the space between the technology's existing material agency (its ability to render text, but not manipulate its placement or draw diagrams around it) and their goal to produce a visually appealing newsletter, the coordinators construct a perception that the technology they currently use constrains their human agency.[9] What do they do? They could decide not to create a newsletter. They could also change their work routines, perhaps altering patterns of information dissemination so that they could communicate the information verbally and, thus, not need a newsletter. But to the extent that the word processing program is flexible (e.g., it is designed to be easily redesigned, the coordinators have the skills to change the code that underlies its functionality, or they have access to people who can make changes to the code for them) they may decide to change the materiality of the technology to meet their goals. Thus, the construction of the technology's constraint arose between the material agency of the existing word processing program (M_1) and the consultants' collective goal (H_1) to create a newsletter. To overcome this constraint, the coordinators changed the technology by giving it features that allow people to make digitized drawings. In so doing, they gave the technology new material agency (M_2); the program now contains a feature that allows people to make digitized drawings. A human agency approach would treat the goal

[9]Note that *constraint*, as it is used here, is not the property of the technology. Rather, a technology that was once everything users wanted or needed is now perceived by them as a constraint to achieving their new goal. This perception of constraint arises because (1) their goal has shifted and (2) they can't figure out how to achieve their goal with the features of the existing technology.

that created the technology's new features (H_1) and the material agency that the technology now has by virtue of those new features (M_2) as constitutive features of the technology (Boudreau and Robey 2005; Orlikowski 2000). Thus, the technology is represented by a square box around H_1 and M_2.

What we begin to see when examining Figure 1 is that the imbrication of an existing material agency with a new human agency (*material* → *human*) constitutes a routine. This imbrication produces the perception of constraint. To overcome that constraint, the consultants change the functionality of the technology thereby giving it a new material agency. Consequently, the imbrication of an existing human agency with a new material agency (*human* → *material*) brings changes to a technology at some level. The coordinators may begin to use the newly changed features of the word processing application (M_2) to produce digitized drawings and, in so doing, begin to construct a perception that these capabilities could afford them the possibility of expanding the readership of their newsletter because of the entertainment value provided by catchy graphics. Consequently, they begin to form a new goal that the readership of their newsletter should expand (H_2). To achieve this goal, however, the group must reorganize itself by changing routines. Some members must specialize in drawing, others in writing copy, and others in laying-out the newsletter to include both text and image. The imbrication of this existing material agency with a new human agency (*material* → *human*) results in changes in the news dissemination routine (e.g., specialization occurs and people increase or decrease their consultations with one another based on their newfound specialties).

As Figure 1 illustrates, the perception of constraints produces a sequence of imbrication that changes technologies while the perception of affordances produces a sequence of imbrication that changes routines. Further, a new agency (human or material) does not just imbricate with an existing agency; rather, it is interwoven with an entire history of imbrications that came before it. Here one might consider that the tiler of a roof does not just imbricate a new imbrex with one existing tegula; she imbricates an imbrex with the entire history of imbrex–tegula relations that came before it, and that history influences, to an important degree, where and how she can place the newest tile. Thus although people can make choices about how they imbricate human and material agencies, the accumulation of choices that were made prior to their decision affect the types of imbrications they can make insomuch as they shape their perceptions of affordances and constraints. When we look at an imbricated system of human and material agencies like the one idealized in Figure 1, we can begin to see how fundamentally related changes in routines are to changes in technologies because they contain the same building blocks, some of which are shared in common. Of course, where one begins reading the chain of imbrications (from a material or a human agency starting point) is somewhat arbitrary, and the chain of imbrications certainly stretches out in either direction. In other words, it is arbitrary to look for beginning or end points in an imbricated system. Instead, the analyst should be more interested in explaining how imbrication occurs and the effects that prior sequences of imbrication have on future actions.

The examples provided above, although entirely hypothetical, begin to illustrate what imbrication looks like, how it might occur, and why different types of imbrications of human and material agencies may produce reciprocal changes in routines or technologies. To move this emerging framework of imbrication from the hypothetical to the empirical, we turn to data collected through an ethnographic investigation into the work of crashworthiness engineers at a major automobile firm.

An Empirical Illustration: Development and Implementaton of "CrashLab" Simulation Technology at Autoworks

This section illustrates how the imbrication metaphor can be useful for interpreting the findings of an ethnographic research study, which investigated activities occurring around a technology built to automate computer simulations for crashworthiness engineering work at Autoworks (a pseudonym), a major automaker located in the United States. Crashworthiness (a vehicle's ability to absorb energy through structural deformation) is assessed by performance engineers (hereafter just engineers) who conduct physical crash tests and computer simulations. Because the cost of administering and recording the data for physical crash tests (building a prototype vehicle, loading it with instrumentation, crashing it into an object, and interpreting the findings) takes so long, Autoworks encourages its engineers to use finite element simulation models to predict a vehicle's crashworthiness and provide recommendations for how a vehicle structure can be changed to increase performance in an impact.[10] The vast majority of an engineer's time is spent in iterative cycles of building finite element simulation models, analyzing their

[10]Finite element analysis is a computational technique that divides the actual geometry of a part into a bounded (hence finite) collection of discrete elements. The elements are joined together by shared nodes. Nodes are the locations where values of unknowns (usually displacements) are approximated. This collection of nodes and elements is commonly called a *mesh*.

performance, and making suggestions for changes in design. To reduce the time and effort it took engineers to set up and analyze simulation models, engineers in Autoworks' R&D Organization developed a new software tool called CrashLab. CrashLab is a tool that is used for pre-processing (setting up mesh models in ways that can be analyzed by a solver to produce desired results[11]) the finite element models that safety and crashworthiness engineers use to make predictions about how a vehicle will respond in a crash and post-processing (how the results obtained from the computational analysis can be extracted in such a way so as to have predictive power) those results. The idea for CrashLab emerged out of Autoworks' R&D Organization in 1995. After nearly 10 years of developmental work, CrashLab was deployed into the user community in September 2005.

Data on CrashLab and the work system in which it was embedded were obtained through the use of ethnographic techniques. I spent nine full months over a two-year period (2004-2006) conducting interviews and observations with people who were involved in all aspects of CrashLab's lifecycle. I began by identifying key informants whom I knew were involved in CrashLab's development, and through these interviews acquired the names of others who were also involved. Fortunately, Autoworks maintained a very detailed and accurate database of employee contact information and I was able to use this database to track down informants even if they had moved into new positions within the company. I conducted interviews with members of five different organizations within Autoworks: Safety, Research and Development (R&D), Information Services (Infoserv), Technology Production (Techpro), and Best Practice Evaluation (Bestpra). Additionally, I conducted interviews with informants in three technology supplier organizations who helped, at various points in time, to build CrashLab. I also conducted several interviews with other individuals who were involved with CrashLab but who were not members of any of these organizations, such as Autoworks senior management, consultants from other supplier firms, and professors at nearby universities. In total, I conducted 58 interviews with people involved in changing CrashLab's features.[12]

I also collected data on the work of crashworthiness engineers before CrashLab was implemented, the activities of developers, trainers, and managers during implementation, and the work of engineers after CrashLab was implemented. During each of these activities I utilized four primary data sources: observations made of informants at work, artifacts that informants produced or used in their work (e.g., screen shots of computer simulations, test request forms, best-practice guidelines), interviews conducted with informants about their work, and logs kept by informants tracking their use of CrashLab. These data collection methods resulted in 134 observations (each of which was three hours or more in duration) with crashworthiness engineers, 51 interviews with engineers who used CrashLab, 17 additional interviews of people such as managers and implementers who were also in some way involved with CrashLab, and more than 500 artifacts used by engineers. A summary of all procedures used to collect the data for this project appears in Table 1. The observational data presented herein are drawn from the work of engineers on a vehicle program I called the Strut Group.

These varied data sources are used to illustrate how the human and material agencies prevalent in the work of developers and users of CrashLab became imbricated and, in so doing, produced subsequent changes in its features and in the routines conducted by engineers at Autoworks. I present these data not to test the framework of imbrication, but to illustrate its value in thinking about how the relationships between human and material agencies are interwoven and how this imbrication leads people to change their routines and technologies. To make this illustration, I intentionally gloss over many of the details relevant to informants' decision-making processes surrounding the development and use of CrashLab. I also push the political dimensions of these decisions to the background in order to foreground the processual and path-dependent nature of the imbrication metaphor. For further details about the development or initial implementation of CrashLab please consult Leonardi (2010).

With these limitations in mind, Figure 2 guides the presentation of data in this paper. Of course, this figure, and the data used to elaborate it, illustrates idealized cycles of imbrication with the goal of establishing a perspective on imbrication, and it should be read as such. I discuss five imbrications through which the human and material agencies of Autoworks' work system became interwoven. Three *human* → *material* imbrications (enclosed by perforated boxes in Figure 2) produced

[11]A solver is program run on a supercomputer that applies equilibrium equations to each element in a finite element model and constructs a system of simultaneous equations that is solved for unknown values to produce measures of a vehicle's performance given the parameters specified in the set-up of a simulation.

[12]Interviews about CrashLab's development rely on retrospective accounts given by informants. Thus, I am limited in my ability to discuss the actual decisions that informants confronted in the practice of their work. I must, therefore, rely on their accounts of their decisions and interpretations of events, even though they are constructed after the fact. This is a limitation of the study, but one that should not diminish the overall value of the case in illustrating the conceptual framework made available by the imbrication metaphor.

Table 1. Summary of Data Collection

Interviews with Developers (By Organization)	
R&D	12
Infoserv	6
Techpro	11
Bestpra	14
Safety	5
Other	10
Work of Engineers Before CrashLab	
Observations	10
Artifacts	78
Interviews	49
Implementation Activities	
Observation	14
Artifacts	4
Interviews	9
Work of Engineers After Crash Lab	
Observations	124
Artifacts	571
Interviews	42
General Interviews	
Managers	11
Designers	5
Vice President	1

changes in CrashLab's features as people around the technology constructed the perception that it constrained their goals. The two *human* → *material* imbrications (enclosed by solid boxes in Figure 2) produced changes in the way engineers at Autoworks interacted with one another as they began to construct the perception that CrashLab could afford them the possibility of changing the way they worked. As mentioned above, these starting and stopping points are arbitrary. I intend to show why one type of imbrication led to another and to use this understanding to explain how it is that the human and material agencies at Autoworks were interwoven and the consequent effects that these imbrications had on the process of organizing.

Imbrication 1 (*Human* → *Material*)

For many years, Autoworks' R&D had placed a dominant focus on the development of new technologies that could be used in production vehicles (e.g., airbag sensors, anti-lock brakes, etc.), but devoted few resources to developing technologies that would improve engineering processes within the company. In 1994, the newly formed Engineering Mechanics Department (EMD) within R&D was charged with this new goal. To more fully understand how crashworthiness engineering work was being conducted and, by association, to develop ideas about what sorts of tools could possibly improve it, developers in the EMD spent the first two months of 1995 working with crashworthiness engineers.

EMD developers noticed that the steps engineers took to preprocess their models (preparing to submit them to the solver) were highly idiosyncratic. Unlike most of the engineers in Safety, these developers worked in an R&D department that focused on scientific research. The timelines for most projects in R&D were much longer than for projects in Safety because R&D was not tied to the stage-gates outlined in Autoworks' formal vehicle development process. Similarly, because engineers in R&D published their work in journals and presented their findings at academic conferences, they were bound to the traditions of academic research, including the need to make their methods transparent and their findings reproducible. Overall, EMD developers came to Safety with an ideological orientation toward crashworthiness work as a

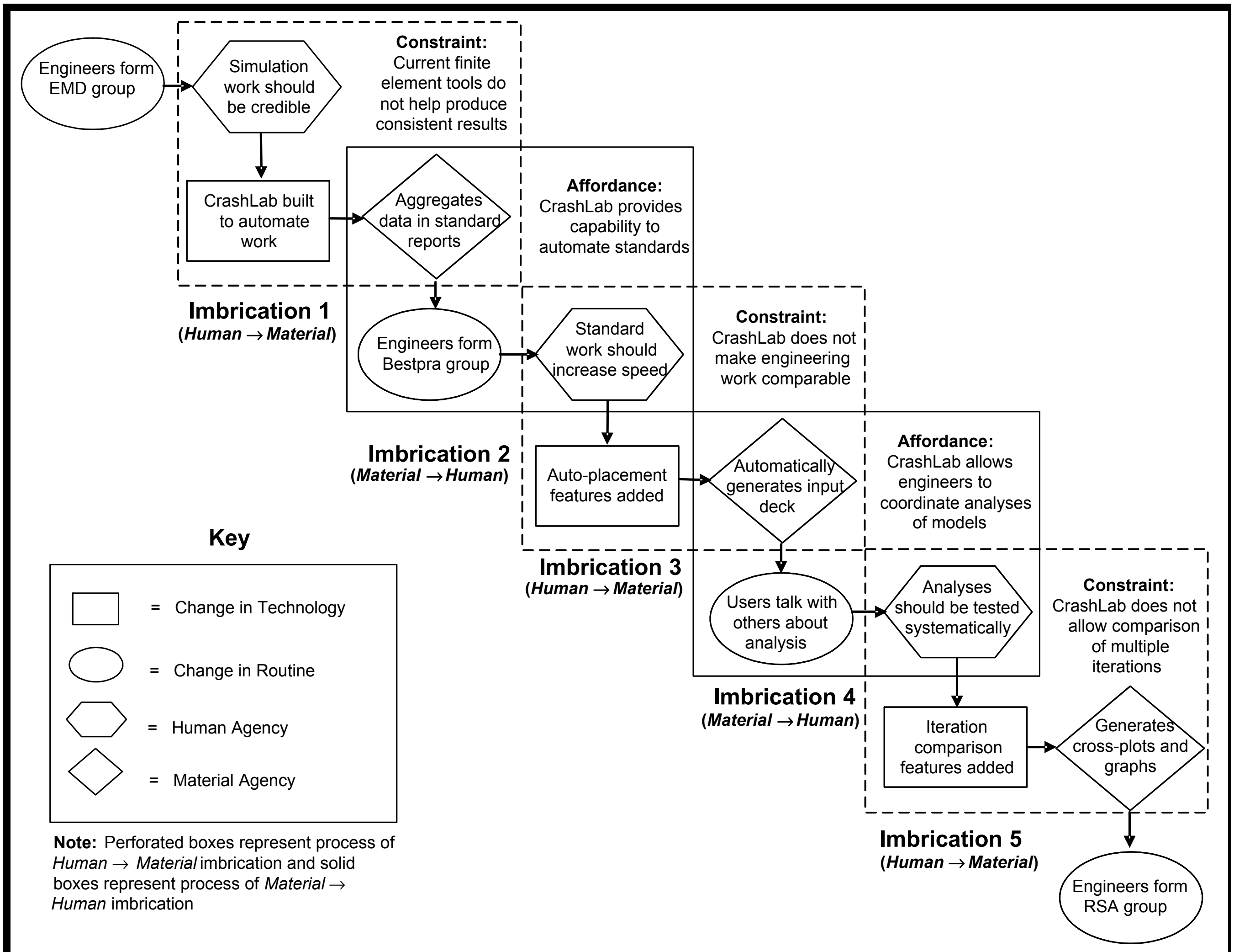


Figure 2. Imbrications of Human and Material Agencies Produce Changes in Routines and Technologies

scientific activity. By contrast, engineers felt that it was far more important to make sure a simulation model correlated with the results of a physical test than to spend time making sure the methods they used to correlate their models could be easily discerned by others. Thus, the institutional background of R&D along with the creation of the EMD, which brought together engineers who interacted around process improvement methodologies, shaped the goals of developers to make crashworthiness simulation work credible and reliable.

With these goals in mind, EMD developers began to notice that the current suite of finite element tools used by engineers to build and analyze simulation models constrained their ability to produce consistent results. When current pre and post-processing tools generated analysis results, engineers only extracted data from them on certain parameters like intrusion or energy dissipation. The results were not presented in any systematic way, nor could they be stored or printed in a standard form. This constraint enforced by existing finite element tools was problematic for EMD developers because, without standard results, the practices an engineer used to build and analyze a simulation model could not be verified to determine their robustness, nor could they be validated by an external reviewer. As one EMD developer explained,

> Crashworthiness work needs to be logically done. Everyone has to do it the same so you know you can

> trust the answers….Using methods people can trust is important. So if you do something different than what is normal, you should be telling this to your people so they can consider it all when they evaluate your results. Most tools don't let this happen.

Thus, EMD developers perceived constraints with the current finite element technologies that had to be overcome in order for them to realize their goal to make crashworthiness simulation work more credible.

EMD developers decided that they could develop a new technology that would work in conjunction with existing pre- and post-processing applications already used by crashworthiness engineers to increase the credibility of simulation work. EMD developers knew that they did not have the structural authority within Autoworks to mandate that engineers had to create standard reports, but they did have the means to impose their goals technically. They recognized implicitly that their goal to make crashworthiness simulations more credible (human agency) could be fulfilled if they created code that would automatically aggregate simulation results into standard reports (material agency) by building a new technology. Over the next three years, EMD developers worked with an external vendor to build a new technology called CrashLab. The interface for CrashLab was relatively straightforward. Along one side of the screen, a flow chart indicating the procedures an engineer had to take to prepare a model for analysis would guide him through a set of ordered steps. As the user moved from one step to the next, a three-dimensional model of the vehicle would appear along the other side of the screen and provide suggestions for how to prepare the model for analysis. To allow engineers discretion without sacrificing the credibility of their models, EMD developers designed a report format that would record any deviations engineers took from the best practices embedded in CrashLab. In its visual layout, the report contained a table entitled "Best Practice Violation." Any parameter in the pre- or post-processing of the model that diverged from the best practices appeared in this table. The second column to the left contained a description of the best practice embedded in CrashLab and the column immediately to its right documented the parameter that was changed. A third column calculated the percentage that the best practice was violated. The purpose of this third column was to give the reader of the report confidence in how close the model used to generate these results was to an ideal test case. Larger percentages of deviation might then mean that the results would not be repeatable or widely generalizable. What EMD developers were most concerned about, however, was not the inherent generalizablilty of the findings, but that the reviewer of the report would know exactly how he could use the results to make predictions for a vehicle's crashworthiness.

Imbrication 2 (Material → Human)

As EMD developers worked to refine CrashLab and add more functionality to the tool, they began to circulate a fully functioning prototype throughout various engineering groups at Autoworks. One of these groups, the Crashworthiness Focus Group, became very interested in CrashLab. Each performance engineering function at Autoworks maintained a focus group, which was responsible, among other things, for endorsing and sanctioning the use of all new technologies used by the engineers in the particular function. The Crashworthiness Focus Group was no different, and according to its formal mission statement aimed to "commonize, improve and manage vehicle crashworthiness simulation tools and methodologies necessary to synthesize and validate Autoworks product designs to meet crash safety requirements." Put more plainly, the focus group actively worked with members of R&D to develop new tools and methods that would aid the work of computer simulation. Importantly, the focus group had final approval of all tools implemented in the user environment by crashworthiness engineers. If the focus group did not deem a new technology sufficiently useful or appropriate for the work of its engineers, it would refuse to endorse it and ultimately Autoworks' IT department could not install the software on engineers' machines.

By the winter of 1998, the focus group had thoroughly tested CrashLab. Whereas the EMD developers wanted to make crashworthiness simulations more credible, focus group members had a different goal. They were interested in standardizing the work of all engineers. Their desire to standardize was buttressed by the hope that standardization would remove human error from the vehicle design process. By interpreting CrashLab's material features through their own goals, Focus Group members began to agree that CrashLab could afford the automation of engineering standards. The problem for the focus group, however, was that although the current material features of CrashLab could afford automation of engineering standards, no standards currently existed to automate. As the focus group's chair commented,

> The problem that I and some others had with Crash Lab was that, I mean, at that time we didn't even have anything standardized.…If we are ever going to have math [simulations] lead the design and reduce our reliance on physical testing, we had to standardize the way we do the simulation work…. And the whole question of quality and accuracy of the results is what drove us to know that the engineers had to start doing the work the same way.

Before CrashLab could automate standard work procedures, Autoworks needed to define what those standard work procedures were.

In early 1999, with the recommendation of the focus group, Autoworks' vice president for global engineering approved the creation of a new engineering organization called the Best Practice Evaluation (Bestpra) group. Bestpra's goal was to create and update standard work procedures for crashworthiness analysis. Structurally, Bestpra sat outside of regular engineering production work at Autoworks. The six engineers who formed Bestpra were given the title of Subject Matter Experts (SME). Their role was to collect information from engineers in Safety to determine what the standards would be for a particular type of analysis. Based on this information, the SMEs began to create a series of documents outlining standards that all engineers should follow when setting up and analyzing models for specific crash loadcases.[13] A typical standard work document was at least 20 pages of instruction on how to best execute practices, from routine mesh generation to more detailed and loadcase specific procedures, such as how to write the appropriate contact cards to specify how the solver should interpret relationships between parts in the model. In March 1999, Bestpra published its first standard work guidelines for frontal loadcases. EMD developers used the best practices identified in this document to determine how to automate the process of setting up and analyzing a simulation model to test FMVSS 208 specifications with CrashLab.[14]

With the SMEs working to create guidelines that would standardize the work of engineers, managers in Safety began to develop a new set of goals. They were convinced that the automation of standardized work should lead to faster simulation model building and analysis because engineers no longer had to take time to discern which practices were most appropriate or efficacious for the job at hand. Standard work guidelines would effectively replace this individual judgment and would lead to an increase in the speed with which engineers could do crashworthiness work. Faster crashworthiness work was preferable because it meant that engineers could conduct more simulations in a given time period than they could before. By doing so, Safety could move from the use of simulations to retrospectively validate physical tests to the use of simulations to prospectively predict the outcomes of physical crashes. Thus, the material agency of CrashLab was imbricated with the human agency of Safety management through the creation of Bestpra, which began a new standard work writing routine.

[13]*Loadcases* are specific conditions through which loads, in the form of energy from an impact, are applied to the vehicle's frame.

[14]Federal Motor Vehicle Safety Standard (FMVSS) 208 is a standard set by the federal government's National Highway Traffic Safety Administration (NHTSA) indicating minimum tolerances that a vehicle must meet in a frontal impact to be saleable in the United States.

Imbrication 3 (Human → Material)

Crashworthiness managers, who took it as their new goal to speed up the way that engineers worked, began to search for clear and feasible ways to make simulation building and analysis faster without compromising the quality of results. For many managers, CrashLab was an ideal IS application with which to carry out their goal because it was easy to envision how the technology could provide capabilities for automation. Given the history of automation in industrial settings and in the automotive industry in particular, it is no surprise that crashworthiness managers looked to a tool like CrashLab to make work faster. The history of manufacturing teaches us that that an essential precursor to automation is the rationalization of tasks. At the turn of the 20th century, efficiency experts such as Taylor (1911/1998) and Gilbreth (1911/1993) pioneered methods to specify and rationalize tasks, breaking a "job" down into its component parts. The insight that tasks could be rationalized heavily influenced entrepreneurs like Henry Ford, who reasoned, following Adam Smith, that if tasks could be broken into component parts they could also be separated and performed by different workers (to increase efficiency) and then reintegrated later. Rationalization and fractionalization of work then led to automation, whereby machines (which could perform component actions more quickly and reliably than humans) performed instrumental tasks and human workers served merely to reintegrate the parts at the end of the line, and eventually to the creation of flexible technologies that could do both instrumental and assembly tasks without human intervention. In a similar way, CrashLab took the standardized (or rationalized) work practices specified by Bestpra and used FORTRAN code to automate their execution with minimal user input.

Although CrashLab automated output of simulation results, it did not automate the practices whereby engineers set up simulation models to be submitted to the solver. Even though the SMEs rationalized crashworthiness tasks by writing standard work guidelines, managers believed that standardization could only increase the speed of work when paired with automation capabilities. As one manager commented, during the late 1990s when simulations of vehicle impacts were just at the point of becoming faster and cheaper to run than physical tests, speed was the goal exemplar:

> Everything here is about speed. Simulations are only helpful if they can be done quickly. The bottom line is that if a simulation takes longer to run than a hardware test, even though it costs more in the short-term, management will always prefer the test. That's because where you really start losing your money is when you don't get the vehicle to

> market soon enough. If you didn't pay say $300,000 for another crash test and instead you waited an extra month for the simulation to be done and so you delayed product launch for 30 days you would lose say something like $5,000 in profit per vehicle on like 10,000 vehicles. So that's, what, like $50,000,000 you just lost? No one would hesitate to do a $300,000 test to save $50,000,000. So the bottom line is it's all about how fast you can do the math.

When bringing their goals to their encounters with CrashLab, crashworthiness managers began to perceive that the technology's features constrained engineers' ability to work faster than they could without the use of CrashLab. In many cases, engineers who were experienced at simulation work could build and analyze models faster by hand than they could if they used CrashLab. Thus, the constraints that managers perceived that CrashLab placed on engineers' abilities to work faster had to be overcome in order to realize the goal of reducing the time it took to build and analyze simulation models.

Crashworthiness managers told EMD developers that CrashLab needed to include features that automated model set-up tasks in particular. To respond to these concerns, EMD developers built auto-placement features into the tool. These features included scripts that would indicate to the engineer using them exactly where an accelerometer or section cut, for example, should be placed per the standard work guidelines.[15] Engineers would then have to simply execute a command indicating that they approved of these locations and the software would automatically write the coordinates into the input deck—a text-based file that could be read by the solver. This automated procedure would eliminate the need for engineers to perform these tasks manually and thus reduce the amount of time it would take to set-up a model for analysis.

By 2003 CrashLab had a new set of features. To use Crash Lab, engineers now had to follow the automated flow of steps that the tool presented to them and also abdicate to the technology the autonomy that they once had in creating their own input decks. CrashLab now automated these steps and engineers who used the tool had no choice but to allow it to do so.

[15]An accelerometer is an electromechanical device used to measure forces in a vehicle impact. In physical crash tests, accelerometers are placed at various areas on the vehicle to measure forces. In a simulation, nodes are selected as accelerometers at which the solver will determine the accelerative forces in the model. A section cut is a plane placed through a vehicle member that is used to measure the force in that particular member (section).

Imbrication 4 (Material → Human)

By the fall of 2005, all engineers who were involved with regular production related work at Autoworks felt tremendous time pressure. Management constantly complained about the number of months in the company's vehicle development process. Every year, senior vehicle architects set more and more ambitious goals for vehicle development stage-gates. These shortened engineering cycles directly affected engineers who were now tasked with producing evaluations of vehicle design that guaranteed increases in crashworthiness performance in less time than they had been accustomed to previously. Despite these shorter design cycles, engineers were not anxious to speed-up all of their tasks. Engineers consistently voiced a valued delineation between activities such as model building or drafting, which required technical skill, but not detailed engineering intuition and judgment, and analysis activities, which required in-depth domain knowledge (i.e., physics, thermal dynamics). They hoped that by reducing the amount of time they spent on routine or tedious model building tasks they could devote the bulk of their limited temporal resources to analyzing the results of their simulations. Such a desire was understandable given that participation in analysis activities placed engineers at the center of decisions about product architecture and design. Being at the center meant that engineers could play a primary role in the vehicle development process, which, in turn, would increase their status within Autoworks.

It was in this environment that engineers in the Strut Group began using CrashLab in regular production work. Consequently, engineers interpreted CrashLab's ability to automatically generate an input deck (material agency) as affording them the opportunity to speed-up model building activities, providing them with more time to analyze their simulation results. Most engineers would open a CAD file in a pre-processing tool, convert the CAD geometry to a finite element data, and then export the model to CrashLab. Within CrashLab's user environment, engineers would follow the automated routines for setting up a model (with instrumentation and load assessment points) and then allow CrashLab to automatically generate an input deck indicating the parameters upon which the model would be solved. After four months of using CrashLab in this way, engineers in the Strut Group were setting up their models in similar ways to one another and nearly all members of the group were using CrashLab. Because their working practices were now coordinated, engineers could realistically talk with one another about their analyses. Consequently, engineers bagan to talk to colleagues about design solutions that had worked in the past and to work together to troubleshoot problems in a given simulation. Consequently, engineers began to increase the frequency with which they consulted each other about design solutions. Consider the following interchange between two engineers. Engineer 1 went to Engineer 2's cubicle to ask if changing the gauge (thickness) of a part would increase performance on a side impact test:

E1: Could I change the thickness of the #2 bar?[16]
E2: That can't go down anymore because of seats.
E1: Okay…
E2: But also if you down-gauge it, it's probably going to deform more and pull. I mean you'll start to see a little bit of a kink between the two front seat attachments for the driver.
E1: Really?
E2: I mean the brackets are 0.8 mm right now. I think the #2 bar is like 1.2 mm, right? You need like a two mil stack.
E1: Yeah, but to beef up those two pieces it would probably take away whatever you gained on the #2 bar, right?
E2: Maybe, but I'd at least start there with the test.

Such new consultation routines occurred commonly across analysis activities in the Strut Group, signaling an important change in the focus of crashworthiness engineering effort.

As engineers consulted one another about vehicle design, their goals began to shift. Because CrashLab's material agency provided them with the ability to conduct coordinated analyses, engineers needed to be sure that they were armed with sufficient data points to engage in helpful discussions. To generate more data points, engineers had to run more iterations of their simulation models. Running multiple iterations was easy to do. After engineers used CrashLab to set-up a model for analysis, they had only to go into the input deck and change the parameters they wished to test in the new iteration. By following this practice, engineers took as their emergent goal that analyses should be tested systematically to provide as much information as possible for use in ongoing consultations with colleagues. CrashLab's material agency was imbricated with the agency of the engineers through changes in their routines around analysis activities.

Imbrication 5 (Human → Material)

To achieve the goal of producing as many systematic analyses as possible, engineers increased the number of iterations they ran for a given crash test simulation. As the number of simulations increased, engineers began to notice that it was very difficult to compare results among them. CrashLab generated a separate standard report for each iteration of a simulation test. By 2006, most engineers ran more than 20 simulations to test a given change made to the geometry of a part or the arrangement of parts in the vehicle, which meant that engineers had to deal with 20 reports generated by CrashLab. CrashLab did not provide capabilities to systematically compare the results of multiple iterations. To make such comparisons, engineers had to use CrashLab to generate 20 separate reports (one for each iteration). Because the reports CrashLab produced were in HTML format, engineers had to manually copy the important data from each report into an Excel spreadsheet. Engineers could then use Excel to generate graphs and plots comparing the simulation results and take this information to their consultations with colleagues to indicate what types of changes (e.g., to geometry or material properties) produced the "best" results.

It became clear to engineers that CrashLab's current material configuration constrained their ability to compare results from multiple iterations in a systematic manner. Specifically, CrashLab did not afford engineers the ability to plot results from multiple iterations in a single chart for the sake of comparison—what engineer's called "cross-plots." Engineers thus began to complain to their managers that CrashLab needed to have these new features. Crashworthiness managers, who were keen on having engineers produce results faster, were eager to champion new features that could speed up work while simultaneously increasing the robustness of analyses. EMD developers were receptive to the demands of crashworthiness managers and began to develop new features in CrashLab that would allow engineers to effortlessly compare the results of multiple iterations. The technical innovation made by EMD developers was to create code that clustered performance metrics from various simulations into one common report and, further, to produce cross-plots and graphs of these data points. Consequently, when engineers began to use the newest version of CrashLab, they found that the tool automatically performed the comparison functions they desired without extra effort on their part. The goal for more systematic analyses characterizing engineers' human agency was imbricated with the material agency of automatic cross-plot formation through the addition of iteration comparison features to CrashLab.

Engineers normally brought the comparisons of their simulations to consultations with colleagues. Slowly, engineers began to notice that the types of design changes that produced good performance for one vehicle were sometimes similar to the types of design changes that produced good performance for another vehicle. Although engineers could provide anec-

[16]The #2 bar is a lateral support (structural member) on the vehicle's underbody.

dotal examples of certain changes that commonly produced good performance outcomes, they had no way of systematically comparing the findings generated by engineers across multiple vehicle programs. As one engineer commented,

> I think it would be great if somebody took all of our results, the ones that work and the ones that didn't, and then do some analyses of them. If they did stuff like that, they could tell us, "Hey, this sort of bracket when it's angled in this way improved performance on 9 out of 10 programs." If they did that, we could incorporate those learnings into our designs. But nobody does that.

As crashworthiness managers came to realize that all of this new data generated through the use of CrashLab could be mined systematically to suggest general design trends for optimal crashworthiness performance, they worked with Techpro, which specialized in the maintenance and deployment of finite element technologies, to develop a new group that could analyze performance data from across Autoworks. This new Robust Synthesis Analysis (RSA) group was formed from a mix of engineers with backgrounds in optimization and statistical analyses. These engineers created new routines for coding, analyzing, and comparing the data that engineers generated in their simulations. By the end of my study in late 2006, the RSA group was planning to develop a new tool called CARDS (Computer-Aided Robust Design Solutions) to automatically analyze the vast amounts of data generated by engineers in their simulation activities.

Discussion and Implications

This article began with the suggestion that employees in today's organizations increasingly find themselves working with flexible routines and flexible technologies. In recent years, scholars have argued that organizational routines are often designed to be flexible (Essen 2008; Howard-Grenville 2005). That is, people can alter the performance of a routine—their patterns of social interaction—while still maintaining its ostensive qualities—the broad understanding of what the routine should do (Feldman and Pentland 2003). Technologies are also increasingly flexible in the sense that people have resources to reinvent, redesign, and reconfigure their material features so that the technology does new things. Thus, when people work with both flexible routines and flexible technologies and wish to change their work practices, it seems that they have a choice. Do they change the routine, or do they change the technology?

The perspective advanced in this paper suggests that the answer to this question depends on how human and material agencies—the basic building blocks common to both routines and technologies—are imbricated. As illustrated in the case of CrashLab's development and use, when an existing material agency is imbricated with a new human agency (*material* → *human*) people may be likely to change their routine, and when an existing human agency is imbricated with a new material agency (*human* → *material*) a technology changes. Thus routines and technologies, although distinct empirical phenomena, are ontologically related in the sense that they are both constituted by imbrications of human and material agencies. As illustrated in Figure 1, a routine shares its building blocks with a technology just as the technology shares its building blocks with a routine. The result is that a change in a technology at any given time is linked to the routines that came before it and will be linked to the routines that come after just as a change in routines is linked to the technologies that preceded and will follow it. If we drop the language of routines and technologies and speak at the lowest level of abstraction, human and material agencies are constantly imbricated with one another and this chain of imbrications occurs in a path dependent manner.

What keeps human and material agencies in a continued sequence of imbrication is that people draw on the infrastructure created out of past imbrications (routines or technologies) to construct perceptions of affordances and constraint. The construction of these perceptions creates a space of opportunity or frustration in which people are motivated to act (Gaver 1996; Karat et al. 2000). To the extent that people have the ability to alter their goals (a presumption that has long undergirded discussions of human agency) and the ability to change a technology's features (a capability increasingly made common by flexible technologies), their perceptions of affordances and constraints may compel them to make new imbrications of human and material agencies, which then continues to produce changes in routines and technologies. This perspective has several implications for a human agency approach to the organizing process.

Incorporating the Role of Material Agency into a Human Agency Approach

For a number of years, IS researchers have been skeptical of talking about technology's material agency because they have not found a successful way of combining the important insights from structuration and actor–network approaches to explicitly theorize the role of technologies in the production, maintenance, and change of the organizing process. The imbrication metaphor recognizes that humans have agency, and operationalizes human agency as people's ability to form and realize their goals. It also recognizes that technologies have agency, operationalizing material agency as technology's ability to act on its own. For human and material agencies to become imbricated, someone has to arrange them in particular sequences. Thus, technology developers and users actively imbricate their human agency with the material agency of the artifacts with which they work, as they experience that material agency in the real-time of their practice.

The ability to recognize the role of material agency within the axiology of the human agency perspective means that the imbrication metaphor may help in specifying why people who can choose to change either their routines or their technologies to better execute their work make the choices they do. Because its material agency is circumscribed by the set of features a technology possesses, the technology can only do so much. As Pentland and Feldman (2008, p. 243) observe, because its material agency is limited by its feature set, a toaster simply cannot be used as a cell phone, no matter how much someone wishes it could be. Thus technologies can only do certain things. Of course, how people choose to interpret the things a technology does, or whether they recognize what those things are, is quite variable. For this reason, a technology's material agency can encourage people to perceive that the technology sometimes constrains their ability to achieve their goals and other times affords them with possibilities to develop new ones. As the case illustrated in this paper demonstrates, a person's perception of whether a technology constrains desired action or affords new action depends on prior imbrications. Without perceptions of constraint or affordance, people would likely continue to use existing technologies and routines in inertial ways. As Orlikowski (2000) shows, to the extent that technologies and routines allow people to accomplish their goals, no change in either takes place. Thus it is important to recognize the role that changing material agencies (enabled by flexible technologies) can play in the ongoing process of organizing. Incorporating the notion of material agencies into a human agency approach helps to explain how people make choices about whether they will change their flexible routines, or their flexible technologies. Moreover, in contrast to existing human agency approaches which see material agency as a potential threat to human agency, the imbrication lens views material agency more neutrally: its influence as either an affordance or a constraint depends on the perceptions people construct about it.

Reconciling Ontological and Empirical Specifications of Routines and Technologies

At the ontological level, scholars are beginning to suggest that routines and technologies are indistinguishable phenomena (Baptista 2009; Orlikowski and Scott 2008). As Leonardi (2009, p. 299) suggests, "technologies are as much social as they are material (in the sense that material features were chosen and retained through social interaction) and [routines] are as much material as they are social (in the sense that social interactions are enabled and constrained by material properties)." Yet, at the empirical level, technologies and routines are relatively easy to distinguish (Edmondson et al. 2001; Pentland and Feldman 2008). As Barley (1988, p. 46) notes, "if one were to ask individuals in actual organizations what technologies they use in their work…the technology would have a name and the informant could, at least in principle, point to an instance of its use." Thus, our current understanding of the nature of the relationship between routines and technologies evinces dissonance between our ontological specifications and our empirical observations.

The imbrication metaphor provides one way to reconcile this dilemma. If we recognize that routines and technologies are figurations (to use Latour's term) or infrastructure (to use Star and Ruhleder's term) created from the imbrication of human and material agencies, it seems more appropriate to make both ontological and empirical claims about the relationship *between agencies*, as opposed to the relationship *between routines and technologies*. In other words, the imbrication metaphor breaks down the walls between studies of routines and studies of technology by suggesting that researchers who investigate them empirically are actually studying the same underlying process: the imbrication of human and material agencies. When we look at the theoretical string of agencies presented in Figure 1, we don't naturally see any routines or technologies; we just see agencies. Of course, our specification of some imbrication of agencies as either a routine or a technology is a by-product of empirical operationalization. Thus, we might be more accurate to first conceptualize organizations as imbricated systems of human and material agencies and, if we start from this point, ask how certain imbrications of these agencies produces particular figurations. Figure 2 performs this exercise by showing how certain human and material agencies were imbricated by strategic actors at Autoworks, as they constructed perceptions of constraints and affordances, such that routines and technologies were constituted and changed.

The benefit of talking about imbrications of human and material agencies is that *imbrication* emphasizes interweaving as opposed to impact. Many IS researchers and even more organizational researchers have seemed tentative in moving technology into a more central role in their theories about organizational routines because they have been unable to speak of its role without resorting to deterministic language (Leonardi and Barley 2008). By suggesting that human and material agencies become interlocked in repeated patterns (as opposed to saying that routines and technologies impact each other at a given point in time), the imbrication lens recognizes that both human and material agencies are necessary for organizing to occur; their imbrication is what produces complementary changes in technologies and in people's interactions.

From this vantage point, students of routines and technology can begin to view structure (metaphorically and literally) as the product of imbrication. Currents in a river have a structure (a direction of flow) that is made visible through patterns of rock imbrication. By examining imbrication patterns in fluvial settlements, geologist can "see" how a river is flowing, how it has flowed in the past, and, in some cases, predict how it will flow in the future. The structuring process is a lot like the flow of current in a river. While the process occurs, there are few visible traces by which to observe it. Firms often try to do so by the creation of an organization chart, which maps ideal flows of interaction based on hierarchical relations, and organizational researchers often use such charts to capture a glimpse of structure at a given point in time. Organization charts, however, only capture the social components of the organizing process. For example, if Figure 2 were comprised only of square-shaped boxes (routines), the only other attribute we would be able to infer about the dynamics of the work system would be the hexagonal-shaped boxes (human agency). We would not know why, over time, the content of the square or the diamond-shaped boxes changed. To know these reasons, we also must treat the square-shaped boxes (technology's features) and diamond-shaped boxes (material agency) as constitutive features of the structuring process. By focusing our efforts on how human and material agencies become imbricated, we can begin to visually conceive what the structuring process looks like. As the imbrication framework suggests, structuring involves simultaneous and interactive changes between the features and routines of the technology. By mapping these changes over time, we may be able to gain new insights into the dynamics of socio-technical change and its role in the constitution of organizations.

Conclusion

Routines are intimately tied to the technologies that enable social interaction because of the imbricated nature of human and material agencies. As this paper has shown, the increasing flexibility of routines and technologies in organizations affords an opportunity to look more closely at the way in which human and material agencies change in response to one another. Their concordant changes, influenced by past patterns of imbrication, constitute and bring reconfigurations to the routines and technologies through which organizing is accomplished. As the example at Autoworks has shown, when both routines and technologies are flexible, human and material agencies are in a process of continual imbrication such that the organizational structures they constitute are always in flux. Thus, as scholars begin to push us to think about organizing as a sociomaterial process, the imbrication metaphor helps us to explain how the social and the material become interwoven in the first place and continue interlocking in ways that produce the infrastructures that people use to get their work done.

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