Between Inspection and Innovation

The Central Role of the Peer Review in Systems Engineering

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Abstract— *Few would argue against the idea that the dominant focus for both researchers and practitioners in the decades following World War II centered on quality control and operational efficiency. In the last twenty years, however, this focus has shifted to organizational innovation and product differentiation strategies in an increasingly competitive market environment. However as this pendulum has swung from one side to the other it passed over organizational activities that I will argue are no less important to organizational effectiveness. In this paper the engineering peer review is presented as an organizational activity that is critical to the success of products in highly complex systems engineering or systems-of-systems environments. Empirical data from peer reviews and a cybernetic framework are used to highlight the unique role these reviews play in the design of complex systems as well as helping to differentiate these activities from quality control (inspection) and innovation. Implications for both theory and practice are discussed.*

Keywords—systems engineering, system design, design review, decision-making, philosophy of technology, cybernetics.

I. Introduction

In this paper a cybernetic view of systems is used to create new spaces within which to conceive of the role of peer reviews (sometimes referred to as "gated reviews") within systems engineering contexts.

Peer review activities differ from quality control (inspection) as well as innovation activities in ways that become clearer from a cybernetic perspective emphasizing the the importance of "direction" (i.e., rules, requirements, specification, expectations) central to any system of control. In inspection activities direction is clearly defined and non-problematic while in innovation activities direction is not yet defined and being formulated. In peer review activities, rather, direction is a contested terrain that must be tested, negotiated, and refined through social interaction or appeals to higher authorities.

This paper uses data from actual systems engineering peer reviews to develop an empirical basis for concepts and themes that distinguish the peer review from other important organizational activities and argues that for complex settings such as systems engineering organizations, these activities are central in offering value to the customers who procure these systems.

II. The Review

A. A Cybernetic View

Norbert Weiner introduced the cybernetic view of systems in which control and the communication of information are their central features [1]. From a physical device as simple as a thermostat to a complex social system such as criminal law enforcement, any "system of control" can be thought of as having four key elements that work together as a control circuit: *direction, observation, evaluation,* and *correction*. For example, the thermostat is set to a particular temperature by the user (*direction* is a desired temperature), the thermocouple senses the temperature (*observation*), and the thermostat compares the directed temperature with the observed temperature to *evaluate* if any kind of *correction* is required such as turning on or off a heat source. If any of the four elements in the circuit are missing, control is lost.

As already mentioned, complex social institutions can also be usefully framed in this cybernetic context. In law enforcement different groups/individuals carry out various elements in the circuit. Lawmakers produce the *direction* (laws/rules), law enforcement officers such as police *observe* whether infractions are occurring, courts with juries and judges evaluation whether laws have actually been broken and may also determine the nature and extent of the *correction* (penalties/sentences), and for more severe *corrections* there are jails or "houses of correction" that carry out this function. The point is that viewing the design of systems of varying complexity as being responsive to the need to establish and maintain control is a very powerful unifying framework.

B. Between Inspection and Innovation

Now consider two different ends of this spectrum when thinking about control in organizational processes. At one end is a well-defined process in which *direction* is non-problematic. For example, the production of a standardized part will need to meet a series of very well defined requirements or specifications. At the other end of the spectrum is a process with ill-defined *direction*. An example of this might be a research and development presentation of a new design to technical leadership that either gets accepted or rejected – the proverbial, "is *this* the rock you want?"

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In the first case we are dealing with tightly controlled processes in which the focal activity is the evaluation of the product against a set of well-defined requirements. In mass production this will often involve quality control methodologies such as Statistical Process Control (SPC) or some variant [2]. Here the primary goal is to detect when a well-understood production process is beginning to go "out of control" based on some special cause of variation that will need to be *corrected*. We may refer to these activities as *inspections*. In the second case things are not quite as tightly coupled because the *direction* (what is desired of the product) is still being formulated. There is a process in which engineers are given a task to "come up" with something that meets vague goals, but exactly what it will be or *needs* to be is determined through the presentation of possible candidates to some technical authority and eventual buy-in or acceptance [3]. We can call this kind of activity *innovation*.

The interesting point to be made here is that the activities involved in the production of most systems engineering "products" do not fit neatly into the inspection nor innovation categories. Consider, for instance, a subsystem that resides on a Department of Defense (DoD) platform. The systems engineer will likely have been handed a set of system-level requirements that have been allocated to his/her subsystem and must then derive more detailed requirements that take into account not only functions that the subsystem must perform, but also other things such as reliability, maintainability, logistics, military standards, and information security. This creates a situation in which this body of requirements constitutes a subset of the *direction* governing what the subsystem design ultimately needs to entail. Beyond this are additional expectations from functional management, program management, and the customer that may never be written down explicitly, but yet are nonetheless widely albeit not perfectly known and understood.

If we consider the "product" to be the design document that the subsystem designer authors, then we could expect there to be some inspection and innovation activities occurring. The document may need to conform to a template and may need to trace to other documents according to some fixed rules, so this product could easily be inspected against these kinds of criteria. The document may also reflect design aspects that could be viewed as innovative – as when a never-before-used technology is introduced to perform a subsystem function that had always been performed by a different technology. Yet, products developed within systems engineering contexts rarely reflect revolutionary changes that we would call "innovation." Rather, most new design features follow a fairly conservative evolutionary trajectory [4].

Therefore the lion's share of what needs to be controlled in these design processes is not inspection (where direction is clear) nor innovation (where direction is being formulated), but rather something in between, and this leads us to consider yet another activity: *the review*.

C. The Review in Practice

In management and in engineering literature inspection (quality control) and innovation seem to dominate [5]. This is understandable when we consider that the core strategy of most commercial organizations is low cost or operational efficiency while for others it is differentiation or innovation [6]. Therefore research into how to achieve these core strategies makes sense for the commercial sector. Yet most systems engineering organizations respond to different environmental pressures and therefore evolve a different core strategy – one in which design and production outcomes need to satisfy a myriad of formal and informal technical requirements within established schedules and budgets.

If we accept this as true, then the question becomes, what is the primary activity that controls for the production of most systems engineering products? This is where we need to take a closer look at the review process. Because there are likely thousands of tangible and intangible requirements for a given product and the interpretation of these requirements is never clear or unambiguous, then it is through various reviews (e.g., customer reviews, in-house technical reviews, peer reviews, etc.) that the ultimate products get conceived, negotiated, and enacted through social processes.

D. The Review in Theory

The review, as a "means to an end," is by definition a *technology*. While a fuller exposition of the literature on the philosophy of technology will be in the final paper, here it is important to note that there is a rich heritage of viewing technology not as a value-neutral means to an end, but also as something that influences how human beings experience the world and conceive of themselves and their world [7]. For example, in his famous essay *The Question Concerning Technology*, Martin Heidegger expands on his basic points from his classic *Being and Time* to claim that in modern times technology compels man to *enframe* his world – or to view all things in it as potential resources to satisfy his ends as opposed to viewing them as beings-in-themselves; as he claims the early Greeks had done [8]. Donald Ihde adds to Heidegger's phenomenological stance in showing how particular technologies directly affect how we experience the world – bringing some things to our attention while excluding other things such as when we use a telescope or watch television [9]. That is, the technology, in addition to being a tool to achieve an end, also shifts the way in which we experience the world as human beings and this will influence how we treat objects in our world and how we ultimately conceive of our own identities.

Therefore, if we think of the review itself as a kind of technology, then how might this technology influence how its users experience their world, each other, and themselves? Returning to the cybernetic framework, the review as a technology can be seen as a means to control the creation of a new element in the world and *what* it is, its ontology, is something that the review process is influencing if not wholly determining.

This paper is part of a larger research program that analyzes data from customer reviews and engineering peer reviews to understand the internal dynamics of the review process and how systems engineering products are actually produced [10][11]. This paper will focus only on the engineering peer review to elucidate its structure and dynamics and answer research question: *how does the peer review differ from inspection and innovation activities and how do we characterize it as a form of technology in a systems engineering context?*

III. METHOD

In the defense contracting industry peer reviews are conducted whenever a particular product (often a requirements specification or design document) is about to be "delivered" to a customer either as a formal delivery or as an entrance criterion to a formal program review. The inspection model has become the basis for these kinds of reviews [12]. Therefore the explicit assumption of these reviews is that all of the technical issues have been resolved prior to the peer review so that the focus of the review is on identifying "defects." However this ideal state is rarely reached and a significant portion or the peer review continues to dwell on technical issues (e.g., requirements, architecture, interpretation of baselines, etc.)[13].

Each peer review entails the distribution of the materials to be reviewed to a group of typically 4 to 10 internal stakeholders. These reviewers provide comments within a peer review database tool. Most comments claim that there is something extra, missing, or wrong in the document however some of them are merely asking a question. The author of the document (product) will try to resolve as many of the comments as he or she can prior to the actual review meeting. Therefore the review meeting tends to focus on those comments that are not easily resolved and require some additional discussion/resolution with the group of stakeholders. The resolution to each comment is captured and the group determines whether or not it represents a "defect" in the product.

A. Setting

The peer reviews that were analyzed were collected from a large defense contracting company that specializes in systems-of-systems integration as well as the design of complex embedded weapon control systems. Most of the programs in the organization have been certified at CMMI level 5 and therefore the formal expectation is that the peer review should be primarily accomplishing an inspection function.

B. Peer Review Data Set

Artifacts from 67 peer reviews were gathered and entered into an Access Database for analysis. The average number of comments for each peer review is about 50. The level of detail of the original comments as well as the comment resolutions provide sufficient data to assess not only what technical issues may have existed, but also how the participants are participating in the review activity.

C. Qualitative Methodology

Grounded theory methods were used to evolve codes and to develop theory [14]. This study is exploratory and does not lend itself to the hypothesis testing approach that is traditionally used in quantitative or correlational methods. Qualitative methods are useful when there are areas of study that are still relatively not well understood.

Each of the peer review comments is a database entry in which in addition to the original comment there is data for the name of the peer review, the baseline of the document reviewed, the author's response to the comment, whether or not the comment is a duplicate, the life cycle activity, and the severity, category, and type of defect if it was determined to be a defect.

The early coding phase was intentionally flexible and reflexive – allowing the data to stimulate thinking about theoretical categories and relationships while also allowing the emerging theory to guide the subsequent data gathering [15][16].

Early analysis of the data have been completed and preliminary results have been compiled.

IV. PRELIMINARY RESULTS

Early analysis shows that consistent with its explicit purpose, a significant portion (roughly 40%) of the comments identify a shortcoming in the product according to some non-controversial rule (direction) and therefore can be considered inspection activities. These include spelling and grammar, rules about the completeness of tracing requirements between documents, and comformance to organizational templates.

Very few comments were found to reflect innovation activities. This is likely due to the fact that any innovation for these products would have been performed in early design phases such as trade studies and concept development. In other words, by the time the product is mature enough to undergo a peer review, innovation is no longer expected nor desired as it would introduce a significant change to an established baseline.

Although further analysis is required, the most interesting activities occurring in these reviews are those in which the reviewers encounter a lack of understanding over what the product should be or what the rules/requirements really are. Sometimes this lack of understanding was overcome through discussions and the reaching of consensus, while at other times the comment was left "open" until more information was obtained or, interestingly, a higher authority was needed to resolve a particular disagreement.

A. Implications for Practice

What this is suggesting is that the peer review activity represents a core function of systems engineering. Above and beyond its role in inspecting products, peer reviews are highly instrumental in negotiating (directing or redirecting) what a product will ultimately be and this can only be accomplished by a group of skilled and knowledgeable participants each understanding expectations (potentially competing directions in a control system context) in competing ways and being able to resolve differences in reasonable ways. Therefore while many of these expectations are formal and easy to interpret, many of them are not and require various forms of collegial social interection to identify and address them satisfactorily. Systems engineering organizations should view this activity as being at the center of their core or the “value-added” that they advertise and provide to customers in a strategic manner.

B. *Implications for Theory*

As we saw, in practice the peer review activity performs a useful and important function for the organization. These reviews are incorporated into the orgnaization’s processes, training, and peformance metrics. Yet, as we discussed earlier, if we consider the peer review (or reviews in general) as a form of technology, then what implications may these findings have for our understanding of technology’s role in society and human interaction?

For one, from the cybernetics perspective, there are some *directions* that are stable and non-contraversial where there are others that are being continually revisited and revised. The review is a contested terrain of sorts for what the product will become and it would be interested to explore how the power of the review participants sways outcomes. This will be explored in the next phase of the analysis.

In addition, the philosophy of technology suggests that we look specifically at a few key questions. First, how does this technology affect how an object (i.e., the product in this case) is conceived? At some level it is a *creation* and becomes a new part of the socio-technical world – a part that needs to operate appropriately within a system or within a system-of-systems. In this regard the peer review reinforces Heidegger’s claim that modern technologies compel us to view objects in our world as resources that are designed to interact predictably with other objects in our world. Second, as the review activity is framing the object as a creation, so to it frames its subjects (the reviewers) in particular ways. For example the “owner” or author of the document is its *creator* and it is his/her creation. Even though the product may not be innovative, it nonetheless is being critiqued by the review activity as possibly having defects and ultimately will offer formal evidence on how skilled and capable the creator is in creating a product. Peer review data do indicate that there is a moderate level of sensitivity to certain comments that could reflect poorly on the creator’s skill/knowledge. Thirdly, the other participants in the review become critics and problem solvers and it is the problem solving in particular that seems to represent the core identity of the systems engineers.

However further analysis will help to more clearly frame the review activity as a form of technology that has its own unique role in the philosophy of technology. Another one of the themes that will be explored in the final paper will be the notion of *understanding* and how the review participants’ individual and collective understanding of their technological and social worlds lies at the heart of systems engineering in particular and perhaps of modern production processes in general. These conclusions are also helpful in explaining why the systems engineering function, in general, plays a critical role in organizations where its “value-added” may not be adequately appreciated by management or by other functions within the organization.

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