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Theorizing about Standardization: Integrating Fragments of Process Theory in Light of Telecommunication Standardization Wars

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Abstract
Standards play an important role within information and communication technology as it becomes networked and complex. No single model has yet been developed to address how successful standards emerge. We propose a dynamic process model of standardization that integrates separate lines of inquiry to standardization activities including Simon's theory of artifact design (D), Weick's concept of sense-making (S) and Latour's concept of negotiation in socio-technical networks (N), and organizes them into a hierarchically organized web of standardization events. We investigate three standardization processes in the telecommunication industry with the D-S-N model to explain the progression of these standardization processes.

Keywords: Standardization, Technical standard, Sense-making, Socio-technical networks, Design science, Process theory, Process models, Failure, Success

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"I have always been in the standards business." - Bill Gates 1991

"[Standardization] is not a linear, straightforward or cumulative process. Iterative cycles and wasted efforts are very usual. I think "chaotic" is a more appropriate word [for the description of the development process] than "predictable" or "planned". This naturally makes the ability to operate in such an environment and ability to understand the process even more important." Participant of 3G standardization 2000

Introduction

Standards have continued to play an increasingly important role within information and communication technology (ICT) as it has become networked, ubiquitous and complex. Multiple theories that have been suggested within the areas of economics, sociology, and management can be used to analyze portions of ICT standardization processes. Their limitation is that they pay scant attention to either the technological innovation and exploration inherent in ICT activity or to the institutional aspects of standard enforcement and exploitation (March, Sproull, and Tamuz 1991) necessary for successful adoption. Consequently, they often fail to analyze all of the necessary events and settings that influence ICT standard *emergence* as a *dynamic process*.

In this article we propose a *process model of standardization that* helps analyze ICT standard emergence as a dynamic process. We conceive *standardization* to be a process of creating a technical standard and (possibly) diffusing it into the market place. A *standard* is understood as a set of technical specifications adhered to by a set of producers, either tacitly or as a result of a formal agreement (David and Greenstein 1990, p.4). The process of standard creation integrates the following three intertwined activities: 1) creation of artifacts that can meet a set of requirements embedded in the standard and formulated by the involved actors; 2) a possible deviation from the current technological trajectory in the form of innovation that opens a new (cognitive) design space; and 3) a mobilization of a set of actors that are willing to follow and embrace such deviations and solutions. A faithful account of standardization processes must rely upon a multi-theoretical framework that integrates these three activities. We suggest that such a framework can be developed by drawing on Simon's theory of design (Simon 1981), the Weickian concept of sense-making (Weick 1995) and the Actor-Network theory's (ANT) idea of mobilization and negotiation within socio-technical networks (Latour 1995; Callon and Law 1989). These three theoretical lenses help integrate models of design and negotiated agreements that align actors' interests, along with the "reading" of new meanings into designs, into the analysis of standardization processes.

We use the proposed framework to examine standardization processes in the dynamic field of telecommunications (Schmidt and Werle 1998; West 2000, Bekkers 2001, Bekkers and Smits 1998, Hanseth, Monteiro and Halting 1996) by exploring three standardization cases. We demonstrate how an analysis of ICT standardization processes can benefit from simultaneously capturing the activities of design, sense-making, and negotiation. Our analysis shows that standardization processes unfold necessarily as a dynamic interplay of these three recursively organized activities. Future standardization studies should therefore be open to theorizing over complex processes by drawing upon multiple theoretical bodies.

The remainder of the paper is organized as follows. In Section 2 we review several streams of literature on standardization and analyze their strengths and weaknesses. In Section 3, we outline the theoretical ingredients of the process model of standardization and discuss the critical activities of design, sense-making, and negotiation. We also show how they unfold dynamically and recursively. Next, in section 4 we investigate three standardization episodes using the multi-theoretical lenses of the standardization model and show how each type of activity is required in order to achieve closure in the standardization process and how these activities are dynamically triggered. Section 5 includes a discussion of the theoretical implications of the proposed process model and how it can be used in future research. Finally, Section 6 comprises a summary of the paper.

Standardization Research Issues

ICT Standardization Defined

ICT standardization can be defined as the process by which two or more actors come to agree upon and adhere to a set of technical specifications of an ICT system, its parts or its functionality, either tacitly or as a result of a formal contract (David and Greenstein 1990). Hence, ICT standards concurrently enable and constrain the behavior of various actors in the future (Garud, Jain, and Kumaraswamy 2000). To achieve such an agreement, actors must do the following: signal their willingness to develop a standard; participate in formulating the principal concept and scope of the standard that makes sense for them; agree on the exact content and form of the standard; develop a contractual agreement for “gives” and “takes” in relation to standardization process and its outcomes; and agree upon what conforming to the standard specification actually means. The form and content of these activities may vary. Further, not all of them are necessarily carried out during the standardization process (Schmidt and Werle 1998).

During any of these steps, some or all actors may fail for a variety of reasons. The process spans several contexts that range from laboratories and R&D departments to marketing negotiations that deal with intellectual property rights, brand names and so forth. Thus standardization, through its promise to coordinate multiple activities that help move new ICT technologies successfully to markets, can erect vast arenas of coordination that need to connect a myriad of actors, artifacts and locations over time and space (Jørgensen and Sørensen 1999).

The actors’ motivation for engaging in ICT standardization is high. Those who are successful in setting ICT standards seize significant competitive advantages and reap monopoly rents, while firms that are locked out of the standardization process or remain laggards face significant difficulties (Schilling 1998). Recently, traditional institutional forms of ICT standardizing have become rife with problems and cannot cope with the increased scope, pace and complexity of the standardization processes (Garud, Jain, and Kumaraswamy 2000; Schmidt and Werle 1998; Werle 2000). ICT standard setting has become a risky proposition as many such processes fail and do not meet actors’ expectations. The typical questions raised in the new situation may include the following: How do successful standards emerge in the ICT? How are competitive advantages accrued from adhering to them? How are they chosen and maintained so that they can enlist a sufficient number of followers and become successful? What processes and institutional forms does one need to put in place to create successful ICT standards? What institutional or contingent events and factors influence the creation of ICT standards? These research questions have posed considerable challenges to researchers in several areas for consequent theory building about standardization including innovation and organization theory, management, economics, and the sociology of technology.

The complexity and dynamism of ICT standardization set specific challenges for theory building. Concepts must be open-ended, but at the same time sufficiently exact to capture the essential features of the standardization processes and their outcomes. They should help us become sensitized to the specifics of standardization and analyze processes that are emergent, chaotic, and involve multiple elements (technical, managerial, economic, social etc.). Critical issues that these concepts should help highlight include those listed here: 1) standardization processes result in agreements concerning technical artifacts that are open to challenge at any point of time; 2) standardization processes are complex and involve multiple heterogeneous activities that include decision making and technical construction, 3) standardization processes unfold over time, space and across diverse sets of actors who do not necessarily share similar interests. We shall analyze three streams of standardization research that have sought to understand standardization processes and their outcomes. In this context, standardization is viewed in terms of either design tasks, social sense-making challenges or negotiation problems.

ICT Standardization as innovation and product development process. An obvious approach to examining standardization is to view it as a form of design that results in innovation. In this case, standardization theory can be derived from the literature dealing with innovation and product development. The major question here is then, how should producers organize specific activities so as to enable an effective design (innovation) of the technical specifications? Not surprisingly, due to its close similarities to traditional R&D, many view ICT standardization processes primarily as innovation processes (Miller and Morris 1999; Rothwell 1994), a linear movement from basic research to product design, manufacturing and introduction (Miller and Morris 1999). More recent models introduced overlapping stages and recognized the influential role of external parties in affecting the process logic and outcomes. The strength of these models is that they cover the whole innovation process from basic research to technology introduction. The weakness of these models is that they lack the concepts needed to identify and analyze intricate events that influence standardization outcomes. Hence, while such models are analytically compelling, they fail to describe the emergent features of standardization that are part of the standard setter's experience (Autio 1997) and lack the concepts required to understand the internal logic through which the process becomes enacted and subsequently results in specific outcomes.

Another group of process models that lend themselves to analyzing standardization processes are those in which product development is modeled as a sequence of phases that are separated by gates representing go/no go decisions (Cooper and Kleinschmidt 1996; Cooper and Kleinschmidt 1988; Cooper 1983, 1993). Such "water-fall" models have been widely adopted in several engineering disciplines and have been particularly popular in ICT areas like software engineering. (Iivari and Koskela 1987; Royce 1970) In these models, an ICT product is observed as it is developed through a linear sequence of steps, though recently the need for backtracking and recursion has been identified (Iivari 1990, 1990) when high uncertainty and product volatility prevail. They do not, however, recognize the multiple stakeholders involved in standardization and the need for finding a common ground for their standardization.

ICT Standardization as a decision problem. Another stream of research on standardization has focused on events and rationalities, which guide standard related decision-making among a set of producers. This is driven by the questions, why did producers choose a specific standard, and what would have been the most rational outcome for such a choice? Most of this is informed by economic theory. In economics, the early literature approached standardization as a rational game between the involved actors (Besen and Farrell 1994). Based on these game theoretic models, the actors' decision to create a separate standard, or to join a standardization initiative, was analyzed using utility models and drawing welfare implications from alternative decision choices (Farrell and Saloner 1988). Another stream has been concerned with the diffusion of ICT and the factors that explain the emergence of de facto standards as a result of actors'autonomous decision-making. These models are often based on the notion of increasing returns (Arthur 1989). They can describe how a specific ICT system gains a lead in the installed base of the technology due to correct timing as well as random events. In the management literature, research has focused on analogous problems of dominant design competition and bandwagon processes (Tushman and Anderson 1986; Wade 1995). Both these areas view standards as products that have entered in the market place. They consequently ignore the ambiguity that precedes the decision phase. In both areas, scant attention has been paid to the processes through which technology specifications emerge and to the factors that influence search and discovery. The research has also largely neglected the subsequent processes of getting the actors to decide which of these processes involves negotiation and enrollment.

Socio-technical studies of standardization.Relatively disconnected from the innovation-driven and economic literatures of standardization, a socio-technical literature has emerged during the last two decades (Williams and Edge 1996; Hanseth, Monteiro, and Halting 1996) often called the social construction of technology research (SCOT). This stream examines standardization as a form of social interaction within a network of actors in which the technology becomes introduced and stabilized in the social system. In this case, researchers have asked the questions, why and how was a specific ICT standard created and what social and technical issues influenced its creation? How did the involved actors understand the meaning of the design and what reasons did they have for their enrollment in standardization processes? How did specific actors become connected through artifacts and commitments during the process and why? Accordingly, research in this stream analyzes why the standardization process follows one trajectory while excluding others and attempts to answer why the standardized technology has adopted its shape (Mangematin and Callon 1995).

These studies often trace down the decisions and commitments that actors had to make when their alignment of interests was at stake in the use and introduction of the technology. Yet, successful alignment is but one possible outcome of the negotiation (Callon, Latour, and Rip 1986; Callon and Law 1989; Latour 1993) and failures of technologies are likely to occur because the network does not *stabilize*. Social-technical network literature thus complements the economic literature and provides a *processual* account of the building of the socio-technical network related to standardization actors. It pays attention to the necessary measures and activities that can stabilize the network. At the same time, it often fails to provide an adequate description of the cognitive and technical challenges related to standardization outcomes. It often does not account for rationalities involved in actors' decision making, i.e. why a specific choice was made or how a design was produced.

Open issues in Standardization Research. Each research stream offers specific insights into standardization. Innovation process models help analyze how activities become organized over time and depict their inherent dynamism through the concepts of recursion and backtracking. Decision theory helps analyze choice rationalities and how such choices in specific sequences may result in different outcomes. Finally the socio-technical models raise the issues of meaning, negotiation and actor enrollment. The strengths of each model can be integrated into a broader process model of standardization for a more faithful analysis. We must accordingly identify activities that embrace all these dimensions of standardization. Moreover, we need a way to organize these activities through the constructs that account for observed variations in standardization processes.

Standardization as a Multi-Threaded Social Activity

Standardization as Design, Sense-Making and Negotiation

The standardization process by necessity includes the activities of design (D), sense-making (S), and negotiation (N) and thereby needs to be analyzed as a process that results in a specific design outcome that exhibits a technical "closure" (technical specification). This closure is connected at all times to broader community level processes of creating significance structures (sense-making) and aligning interests among actors that enter the standardization arena (negotiation). These elements are outlined in **Error! Reference source not found.**.

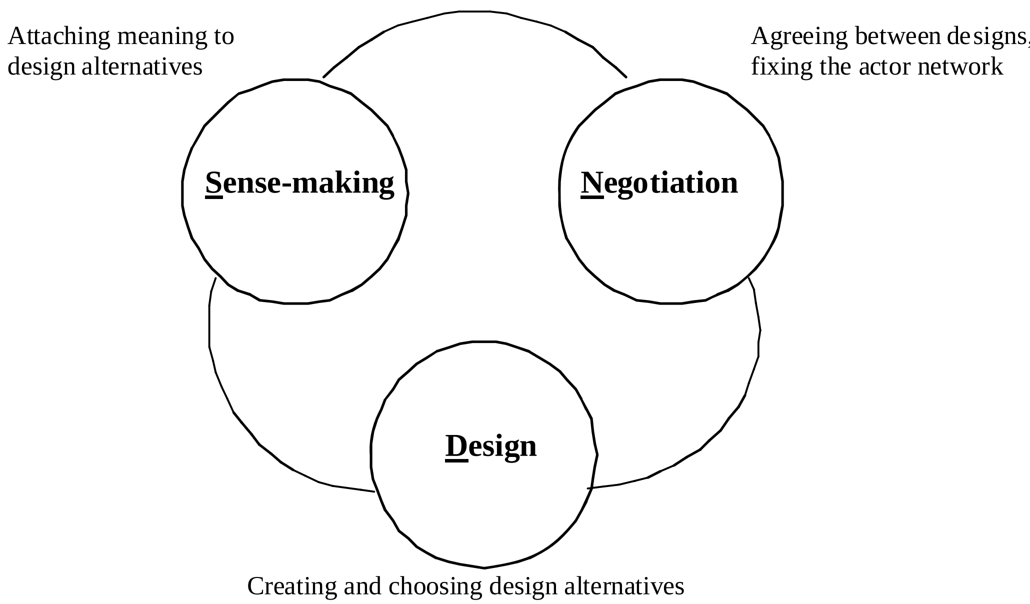

Figure 1. Standardization Activities

First and foremost, developing a "technical specification" – a standard – is about *designing a technical artifact* (D-element). The specification contained in the standard represents the generation and evaluation of choice among technical alternatives and their functionality/ability to reach a closure in the technical specification (Williams and Edge 1996). For example, the design of a mobile phone standard involves the pain-staking process of designing an overall architecture for the system, all interfaces and their functionality between different components and their non-functional features (like reliability). The concept of standardization as design focuses on the cognitive tasks of how to articulate alternatives, make choices among them and evaluate them under conditions of bounded rationality.

At the same time, any investigation of standardization needs to recognize its *social* and *community dependent nature*. As the definition suggests, a standard is formed on the *agreement* between *two* or *more actors.* For example, in the case of mobile phone standards, the actors must observe who can or should enter into the agreement about the standard, why, and under what conditions. Therefore, concepts mobilized in order to analyze standardization must describe necessary social activities that identify and enroll actors (producers) and conditions under which they can reach an agreement (Hanseth, Monteiro, and Halting 1996). Standardization studies must describe interactions between actors that may or may not share joint interests. They also have to demonstrate how the design of standards is contingent upon and influenced by the surrounding and preceding social processes of "reaching an agreement." This requires the capability to provide reasons for doing so for each involved actor. Accordingly, we need to conceptualize standardization in the "context" of design as a set of related activities that lead us to understand what is articulated between actors and why and how they reach agreements as a result of these communications.

Reaching an agreement on design requires that involved actors are able to *make sense* of the designs, other actors and the environment. This we call the *sense-making* element (S-element). For example, in the case of mobile telephony actors must be able to foresee a world where a mobile phone and its use make sense (is plausible) by some set of actors and at the same time create meanings attached to that technology (like business-like, expression of freedom etc.). Such sense-making implies that actors create and enact new frames of reference and significance that will be attached to the technology. This process involves articulating and interpreting beliefs, cognitive elements, standards of evaluation and behaviors that frame subsequent design activity (Bijker, Hughes, and Pinch 1993; Karnoe and Garud 2001). In addition, standardization researchers must analyze how emerging designs and their interpretations between actors become shaped and contested in *negotiations* due to actors' conflicting interests (N-element). For example, in the case of mobile telephony different actors may have different interests and associated ideas regarding the extent to which mobile telephony is or should be different from established modes of uses and meanings attached to wire-line telephony. Without the idea of actors' different "interests" and contrasting ways to make-sense there would be no need to "reach" an agreement. Thus, standards as agreements entail that actors negotiate meanings related to the technology and, during such negotiations, recognize and reconcile their diverging interests. Hence, *negotiation* is needed as the third element of standardization activity.

It is important to understand that each activity (D, S, or N) is dependent upon the other two. None of them can proceed without the support of other activities at an actor's disposal: discovering a new or deviating course of action through design is always subsumed within the idea of a new interpretation of the design context and the obligation of getting others to agree to go along with it. Hence, the focus on a designer's cognitive design behavior in Simon's (1977) design model needs to be expanded in standardization analyses to include concepts of sense-making within participating communities (Weick 1995) and negotiation where their interests are continually aligned (Latour 1995). Successful standardization accordingly implies a closure in each of the following: 1) obtaining a design contained in the standard that meets normal requirements set for technical specifications and can embed novel technological elements; 2) involved actors understand the standard and its implications for their going concerns and they can imagine scenarios in which the standard is illustrated; and 3) involved actors reach an agreement that can stabilize and mobilize a socio-technical network implied by the standard. Each one of these is, however, continually open to re-evaluation and challenge in terms of a potentially better design, emergence of a novel and surprising meaning or an unexpected breakdown where interests are not reconciled or actors do not agree. Such failures normally imply that a new round of standardization involving design, sense-making and negotiation is initiated to re-align all activities and their outcomes.

Standardization as an Emergent, Recursive Process

The three activities of standardization may become related in myriad ways. Concepts that describe connections between activities must help organize them in a dynamic and hierarchical order. We adopt recursion from Simon's seminal work (1977) to provide a framework to organize standardization activities. Simon describes recursion in decision-making as follows: "problems at any given level generate sub-problems that, in turn, have their intelligence, design, and choice phases, and so on" (Simon 1977, p.43). We can observe that he does not impose any specific order in which the three activities are carried out. Second, the activities can be broken down into any set of hierarchical levels that embed these three processes. Third, actors can engage concurrently in several activities, jump back between them or omit some activities entirely at certain moments. If we replace the intelligence, design and choice above with design, sense-making and negotiation as the three recursively organized activities of standardization, we ascertain that there is no specific order in which D-, S- and N elements can be organized. Second, the outcome of any activity can be broken down into lower level activities which can also serve as input to any other activity including the activity itself. This also implies direct recursion. For example, one can design a design, or negotiate how to negotiate. Third, each actor can be engaged in several activities at any point of time and withdraw from some of these activities as well.

We show how this model can be integrated with the product oriented innovation models of standardization. It provides examples of each standardization activity within each innovation stage. The table also covers a product (or in our case standard) introduction and adoption step called "Market Introduction and Adoption," which addresses the need to understand customer-related agreements that fit our definition of a standard.

The concept of inherent recursion of standardization activities has specific implications for the analysis of standardization. First, during the analysis one of the activities is always placed on the foreground while the others remain as a necessary backdrop. This covers the engaged actors as well as the researchers analyzing the situation. This focus can be changed by the involved actors and the observant researchers if required and generally results in a new and different direction for the process. Hence, at each step (actors can make a choice and change the direction of the process by changing the activity and the analysis must lead to the identification of such moments and understand the occurrence of such outcomes. An additional feature of the model is its indifference to the chosen units of analysis and granularity of activities that follows from the hierarchical organization.

	Design	***Sense-making***	***Negotiation***
Initiation	Decision to engage or to retreat from design Setting up the goals and constraints that define the design space	Creating a joint understanding of why a standard is beneficial to different actors Defining the meaning of the technological Artifacts embedded in the standard	Reconciling the concept of the standard with incentives of the participating parties
Requirements discovery	Setting the standards requirements and functional / architectural features	Setting the scope of the innovation and defining its nature and functionality in the possible use context	Reconciling actors' technical abilities with their vision of the scope of the innovation
Resource allocation	Resource planning and commitment	Developing a vision of general resources needed and developing a sense of the complexity and uncertainty involved	Creating options on benefits' and how resources are distributed
Specifications development	Designing the specifications for each functionality and feature of the specified standard	Making sense of technological alternatives and their implications for artifact construction	Negotiating between competing technical solutions and resolving related IPRs Enrolling allies to support chosen design
Standard implementation	Gaining commitment to implement the standard Prototypes and technology trials Alternative technology evaluations	Creating a common understanding with the implementers about the specifications and the vision behind the specifications	Designing alternative implementation plans and negotiating implementation paths Enrolling different groups that are necessary to get the standard implemented
Technology introduction based on standard	Technology design and introduction for large scale uptake	Creating a vision of what the product means for adopters	Developing and negotiating business cases for adopters

Table 1. Standardization and Stage Models

Standardization as Design

Analyzing standardization from the view-point of design is critical to understanding how standards *qua technical specifications* emerge. During the design phase, actors plan and commit to a specific, new and innovative course of action. Such efforts can range from small design steps, such as the design of a specification for a critical component in a GSM phone like a speech codec to designs that involve a broad trajectory of innovation, e.g., the service model underlying a GSM system. Every such step involves generating, evaluating and choosing between different technical and (socio-technical) options (Williams and Edge 1996, p.866).

Accordingly, standardization as design involves "finding occasions for making a decision, finding possible courses of action, choosing among courses of action" (Simon 1977) that are continuously mediated by various representations of technical specifications (artifacts). Standard producers seek to master the complexity of designs through a "divide and conquer" approach by engaging in the following three phases of design: 1) *intelligence* - making sense of the environment and attributing meaning to actions and conditions that call for a design decision; 2) *design*[3] - inventing, developing, and analyzing possible courses of action through crafting technical specifications; 3) *choice* - selecting a particular course of action from those available design options. For example, in the case of GSM, actors had to invent and analyze several options for speech codes or coding methods and at some point make a choice between them. This process was initiated by the need to meet specific envisioned needs that related to cost, speech quality or other use parameters.

Design anticipates that during negotiation each actor weights design alternatives against a set of criteria that may cover economic, political, social and technological criteria. These criteria describe reasons an actor can give for choosing one option. At the same time they signal reflective announcements of background sense-making processes. Such rationales may include maximization of economic profits. For instance, during the choice whether to standardize or not, an actor may consider whether intra technology competition will be more profitable than inter technology competition (Besen and Farell 1994). From the viewpoint of negotiation, actors' designs anticipate others' designs and seek to change the selection criteria between designs. For example, in the case of GSM, many proposals for specific components of the system like speech codecs were at the same time responses to other existing proposals or attempts to develop new criteria by which to evaluate these components.

While ultimately every actor has to individually commit to a design, in a multi-actor setting, several mechanisms can be exploited to coordinate designs. For example, Farrell and Saloner (1988) analyzed how market, committee and hybrid mechanisms support the coordination of multiple actors.[4] This raises the need to distinguish between alternative design modes that describe the governance mechanisms through which a design is produced (see also Benkler 2001). The mechanism could be voting by majority, consensus, consent, etc. These can be supported by structuring mechanisms that enable distribution design like modularity of designs, their granularity or cost of communications (Benkler 2001). This links the design continually with negotiation because there are specific arrangements and negotiation tactics that can help reach and enforce agreement on designs.

Standardization as Sense-Making

Weick (1995) defines sense-making as a process of invention or the creation of a sense that results from an individuals,' or a community's response to changes in an environment. For him, sense-making is mostly re-active in that actors try to make sense of past events and situations, thereby becoming oriented with the current environment. In the context of standardization, this definition must be expanded because much of the sense-making in standardization is proactive; it is about attributing a meaning to a not-yet-invented technology. Much of this is based on proactive readings of past events and exposures to specific technologies and their uses. But it is also a question of expanding the "horizon" (Gadamer 1975), an effort that enables actors to become aware of the prejudices they bring to encounters with the technology. As a result, they become aware of these prejudices, begin to expand their limits of

[3] Simon calls this design as his model is driven by the decision making metaphor. On some occasions, however, he equates decision making with design so there is no contradiction in using the term design in the first meaning.

[4] The episodes and locations of design can also change. In most cases of open or inter-organizational standardization, some design is carried out by individual actors within the organization while some design can be carried out within the standardization meetings and committees or in specific locations that have been established to carry out the design. This analysis is, however, beyond the scope of the paper.

the language and thinking and ultimately become open to new meanings that can be attributed to the technology. Hence, sense-making in standardization is about reading the history of experiences and encounters with technology in a new context which calls for new sense-making and the creation of a new technological and social world.

In the context of standardization, sense-making results in creating and enacting novel frames of reference and meaning in relation to potential and produced designs, processes, or actors. It comprises transforming and renouncing beliefs, cognitive elements, behaviors and standards of evaluation (Bijker, Hughes, and Pinch 1993; Karnoe and Garud 2001); it is a mindful deviation from established frames of reference (Garud, Jain, and Kumaraswamy 2000). Actors also constantly rationalize what they are doing in relation to this image based on conflicting and uncertain information (Weick 1993, p.635; Latour 1995; Callon 1986).

During standardization, meanings are ambiguous and fluid. The standard can accordingly take varying shapes and drastically change over time (Garud and Karnøe 2001). These significations embody ideas about a possible space of design. For example, with mobile phones such significations involved establishing a new vision of wireless service that consisted of mobile phones, antennas, switches, batteries and telephony networks (Haug 2002) that deviated significantly from the established model of wire-line telephony. These technologies had to be associated with visions of their future use that, in the early stages, involved scenarios of using the mobile telephony through the same use process as traditional telephony with the additional feature of supporting mobility across networks (Haug 2002). This was later on replaced and expanded with radically different use scenarios like personal telephone numbers, separation of telephone terminals and service etc. At the same time, the economic implications of planned wireless systems had to be envisioned based on future technology that did not currently exist. The creation of such scenarios expands alternative design spaces, thus creating permanent tensions within the dominant design framework ((Fransman 1999) calls these visions).

Sense-making takes place in all stages of standardization including the adoption and use of the technology due to its “interpretive flexibility” (Bijker, Hughes, and Pinch 1993). The need for interpretation, the creation of a new sense of what the technology is about and what its economic implications are dominate the early phases of standardization. Later negotiations, surprises and novel technological opportunities, use experiences and economic information force actors to continuously question their established frame and continuously develop new readings.

Standardization as Negotiation

Standardization involves developing a new repertoire for technology use, for assigning roles to others in such repertoires, and for trying to in Latour’s term(Latour 1995) enroll them . When these repertoires are formulated, relationships with others must be re-evaluated. It takes place whenever an actor positions himself (or itself) to be a part of the network that results from standardization or tries to become disassociated from it, i.e., their identities and roles become constantly re-negotiated and redefined. Actors need therefore to continually rethink, or make sense of,, their relationships with others so that the network implied by the standard permits its mobilization (Hanseth, Monteiro, and Halting 1996). Thus, mobilizing or “performing” the actor-network as a part of a sense-making process creates the negotiation space for actors in which they relate the designs to actors and to their different interpretations of the technology (Callon 1986; Latour 1995). By establishing sufficient commonality in interests and thereby mobilizing the actor-network often demands the ability to compromise[5], and thereby reach an agreement (Weick 1995, p.43) in the form of *a standard*. During negotiation actors bargain the distribution of future inputs and outputs to reach an agreement in relation to the designs that have emerged. This normally takes the form of choosing specific designs, identifying associated intellectual property rights and their nature (see e.g., Bekkers 2001) and agreeing on the normative framework that defines commitments and obligations of different parties. Such negotiation involves, at the same time, the capability to envision, connect and fix a socio-technical network, which "inscribes" the chosen agreement (Latour 1995) and distributes and maintains specific rights and obligations for different actors and their relationships to technology. For example, in the case of wireless technology standardization, agreements on specific compatibility requirements in critical network interfaces (terminal, base station, switch, backbone network connection and switch) have to be agreed upon in the technical specification. Concurrently, associated property rights and their implications for the possible commitments, obligations and rights of different parties must be observed. This implies that all actors who had an interest over those interfaces including regulators (frequencies and radio interface), terminal manufacturers, telecommunication manufacturers, chip-makers, operators and wire-line system standard developers have to be enrolled and a specific normative framework defining their relationships must be established[6].

Each actor seeks to maximize his benefits in "coming to an agreement" that during sense-making was only imagined, but now has to be embedded into the material and social network. But because the envisioned world implicated by the imagined solutions is not real or fixed, it is continually up for grabs: "The entities identified and the relationships envisaged have not been yet tested. The scene is set for a series of trials of strength whose outcomes will determine the solidity of … the problematization" (Callon 1986, p.207). These trials of strength translate the concerns of one world into those of another and then discipline the translation in order to stabilize a socio-technical network (Star 1991).

Empirical Investigation of Standardization Using D-, S-, N Model

We will now analyze three standardization cases in the telecommunication industry. The goals of this analysis are threefold. First, we want to show that standardization processes can be broken down into D-S-N activities and involve a dynamic interplay between one another. Empirical evidence from the cases helps illustrate the detailed working of design, sense-making, and negotiation in standardization efforts. Second, we want to show that, by applying the D-S-N model, we can analyze standardization processes in terms of complexity and recursion. We seek to illustrate how a singular D- activity can be expanded to include complex recursive process structures. Third, the case studies enable us to contrast real world standardization processes with normative process models of standardization that often depict standardization processes as linear.

[5] From the viewpoint of game theory not all standardization negotiations are zero-sum games and hence there is not always a need to compromise or make trade-offs.
[6] This does not exclude the possibility that in some situations the process evolves as *quid pro bono* and is based on what Benkler (2001) calls "peer production," which has been widely adopted in the open source community. This would be one different kind of normative framework with different types of normative implications.

Methodology

Our use of case studies was motivated by both our concern for process analysis and simultaneous theory building. While in this paper we present the cases as illustrations of the model we developed, the research process more closely followed grounded theory methods. We developed our theoretical arguments through the interplay of data and theory. Our research concern was in explaining and understanding highly complex processes that unfold over several years. The case based method is uniquely suited to capture the richness and complexity of such processes (Yin 1994).

We selected three cases of standardization from the wireless telecommunications domain. This domain was chosen since it often combines elements of formal standardization and de facto standardization. For the purpose of this study, we selected the standardization of the analogue Nordic Mobile Telephone (NMT) system and the digital GSM standard, which were the main wireless telephone standardization efforts in Europe. The third example deals with the development of the short-range radio standard called Bluetooth. This standardization initiative had its origins in the independent efforts of several wireless phone manufacturers to develop short-range data transfer capability.

Our cases thoroughly cover various standardization modes on a continuum ranging from market driven de-facto standardization to committee driven standardization. The three cases differ significantly also in the complexity of the technology involved, the number of industries, individuals and firms enrolled and the timeframe assigned to each case. Furthermore, the three processes cover the last three decades, namely, the 70s, 80s and 90s, during which organizational structures of standardization organizations and participating actors have changed significantly. This has inevitably led to changes in the underlying processes, including the inter- and intra-organizational standardization processes. For a more detailed description of these cases, see appendix 1. Key features of each case are outlined in **Error! Reference source not found.**.

Case	*Type of standard/fora*	*Size of fora[7], persons*	*Cultural settings*	*Time frame, years*
1. NMT	Committee, de-facto	10-30	Nordic, homogeneous	10+
2. GSM	Committee, de-jure	30-100	European, heterogeneous	10+
3. Wireless link	Alliance, de-facto	15	Cross-continental, heterogeneous	2

Table 2. Cases Summary

We collected a rich data set on these cases through several methods. First we conducted multiple interviews with managers[8], who were either key decision makers or standardization specialists. In addition to interview data, written documents, memos and public announcements from firms involved in the standardization cases were collected and analyzed. Finally, we utilized secondary data from industry analysts and trade publications. These additional data sources were used to triangulate findings from interviews whenever possible. Concepts were used to interpret data and develop an account of the observed behaviors and outcomes. This

[7] Number of people in technical committee, responsible for specifications' development

[8] For instance, in the cases of the NMT and GSM cellular telephone systems, former chairmen of the standardization committees were interviewed. For confidentiality reasons, we cannot disclose all the names of the managers interviewed.

strategy of inductive theory discovery, coupled with the continuous interpretation of observations through the lenses of outlined theories, allows the development of a detailed theoretical account of the phenomena (Eisenhardt 1989; Glaser and Strauss 1967) that is analytically generalizable.

Standardization Analysis Using the D-S-N Model

Standardization Processes can be broken into Design, Sense-Making, and Negotiation Activities. Our model suggests that each activity is essential for standardization. Sometimes they overlap, while in other instances, they can be clearly separated. Bluetooth provides an example of a situation where design, sense-making, and negotiation took place concurrently. During the early stages of the standardization process several manufacturers realized that this technology could become important for other mobile device manufacturers as well. Independent of each other two mobile phone manufacturers contacted a semiconductor manufacturer to discuss the possibility to develop a standard that one could utilize across industry boundaries. Facilitated by the semiconductor manufacturer the two competitors realized that cooperation would enable a creation of a standard would have enough weight in the market. As one interviewee observed:

> "With Ericsson we work in the same business area – the phones and the cellular terminal devices. We didn't go to each other to start it. We went originally both to INTEL. But what was important in forming the consortium, all the companies who joined had developed the vision that in order to make this really successful, we would need to have a common and open standard for it. Something that is proprietary for one company well it might gain some market and it would bring some benefits to that company but it would not really make it widely adopted."

Based on this sense-making, the three companies started negotiations about whom else to include in the standardization work. Different alternatives were considered to trade-off the difficulties of negotiating a standard with a large number of companies while at the same time ensuring wide industry acceptance. The three initial companies chose that the standard should be created by a small network to avoid problems of having to negotiate details of the standard with a large number of actors. This would delay the process and make it more difficult to "perform the network".. This decision led these companies to invite additional companies from the portable PC market to join the consortium.[9] The choice of these companies showed how they related their sense-making and attribution of the significance of the technology to their own interests of getting it accepted and move it fast into the market.

The simultaneous need for integrating negotiation and a design space into the standardization effort shows how technological, social, economic and political rationales became intertwined through the intersections of the three activities. The two computer companies that joined early on the consortium were selected not only for their technological and market strength, but also for their good relationships with the semiconductor company. In the words of one interviewee:

> "Certainly these two companies are driving the technology and the new features in their devices. One thing of course is that they have good and direct links with INTEL. They are important

[9] Also other manufacturers where contacted to participate in the standardization effort but they ultimately declined.

> customers for INTEL. There are other companies who are using AMD chips for example - buying chips from INTEL's archrival. I think that these companies, if I know it right, are also good friends of INTEL. In that sense they are politically correct."

Whereas technological strength and design capability clearly plays a key role in the choice of actors – the early configuration of the actor network –, their impact on the economic viability of the future standard, their current economic and social ties and the avoidance of political conflict in the alliance all strongly affected the final choice.

While the above example shows how sense-making, negotiation and design become seamlessly fused, the following vignette that Thomas Haug — a secretary of the NMT group and later a chairman of the GSM committee— recalls shows how these three activities had to sometimes be separated in order to allow progress towards closure in standardization. Based on the results of the early sense-making process, NMT developers had to refine their specifications:

> "We realized that we would probably have a lot of mistakes, when we wrote specifications, so we sent out some early versions. And we invited the suppliers to the discussions. It was not very successful – it was a total failure! It was [a failure] because we invited all the manufacturers at once to a big meeting. We presented our ideas to them, and got no questions. Because, of course the fact we had not thought of, that no one would really run the risk of disclosing to his competitor what he was thinking of. But later on, we started to invite them one by one. And that was very fruitful… And after each meeting we issued a new set of questions and answers, without mentioning who put the questions to us. And we gave a list of answers that we'll give them. And that was the information they had."

In this quotation, the negotiations about technical details had to be separated from sense-making in terms of their meanings for different companies and the resulting configuration of the actor-network. To achieve this separation, the information exchange was later on organized in a way that enabled the system developers to crosscheck any particular technological solution for feasibility with other manufacturers while avoiding disclosure of immediate answers. Thus, those meetings were a punctuated series of design and negotiation processes aimed at refining the standard based on the outcomes of initial sense-making processes.

Design, Sense-making, and Negotiation can unfold in a Non-linear Fashion. We argued above that D,S,N sequences do not necessarily unfold in a linear fashion. Rather, any activity can trigger any other activity. In the following vignette, the standardization committee had to resolve conflict over different radio coding and air interface solutions. These decisions form the cornerstone of any wireless telephony solution and are thus a seed for both technical and political maneuvering. In 1987, the GSM group reached an impasse between a Franco-German radio coding method and a Nordic design[10]. This choice implied different tradeoffs between quality and the cost for user terminals and suggested a significant impact on the network architecture and cost. French and German PTT representatives privately favored the Nordic plan because it made sense from the viewpoint of trading between quality and cost. Yet, their governments opposed this choice due to the R&D investment made by French and German governments and manufacturers in the specific technology option proposed. Due to the dispute over the coding methods and air interfaces, the whole standardization process came to a halt for nearly six

[10] It must be noted that the radio coding method is an essential part of a standardization process as it affects the efficiency and voice quality of the radio link (circuit) between the mobile terminal and the base station.

months. The Franco-German technology option, however, was abruptly abandoned when Germany changed its position and endorsed the Nordic plan (Manninen et al. 2000):

> "In February 1987 we had a meeting, which ended in disagreement. Germans and French wanted a wide-band system, and the rest of the Europe wanted a narrow-band system… The technical people in GSM agreed we should have this narrow-band system. It was in interest of compatibility. But political people dictated the opinions of PTTs. And they had a lot of political reasons. They've spent a lot of money on the experimental systems and they wanted something to get for their money"…

In the quotation above we see how parties, while engaged in the negotiation of technological designs, attempt to enroll allies and use powerful fixers. This negotiation triggers sense-making related to investments made during the resource allocations that took place earlier. The continuation of this vignette shows how, after new sense-making and bringing new rationalities into the table that helped to overcome the earlier fixated reading of the situation, a new round of negotiations took place so that the process could achieve closure (Manninen and Fomin 1999):

> "In June 1987 all these difficulties had been resolved, The German and the French ministers had met. They had agreed, after some gambling perhaps, that in the interests of compatibility in Europe, we could not possibly have a French-German system [which would be different from the rest of Europe] right in the middle of the continent… And then in order to give them something for their money, we agreed to switch from one mode to another mode for digital transfer. It was a face-saving, I think."

The example above also shows how economic, political and technical criteria figure into agreements while actors have shifted flexibly between D-, S- and N- activities. While the narrow-band solution was clearly superior from the technological and cost perspectives, it entailed economical losses of investments in R&D carried out by German and French companies. The switch to another mode for digital transfer – a design compromise made during the negotiations – made this decision politically bearable. These compromises were necessary simply because the multilateral maximization of all benefits is not possible – even in the case of competing technological designs. Another important implication of the example is that the choice that is seemingly a minor part of a design creates important path dependencies for the later designs (Liebowitz and Margolis 2000).

To Proceed the Cycle of Design, Sense-Making, and Negotiation needs to be Complete. Any standardization process must successfully reach closure in order to become a standard. Moreover, this must occur for all three activities. Standard makers (what is the antecedent of "that?" Unclear what you mean here) must also reach closure at any specific stage of standardization if they want to proceed. For instance, the initial resource allocation sense-making efforts center on forming an understanding of what resources and skills are necessary to develop a standard in terms of the size of the project and the type of resources needed. Bluetooth standardization provides a good example of how such sense-making takes place. Early on, the original founders of the Bluetooth alliance discussed which partner should enter the core to ensure the effective development of specifications. Based on the technological vision (sense-making) that Bluetooth would constitute an initiative that would cut across industry boundaries, the firms were trying to find a structure that would provide necessary resources, but keep the actual implementation arrangement simple. The following quote underscores this:

> "Of course there was the discussion what is the optimum size for this kind of consortium. First, it has to be so big and it has to have so strong players that it really has the market and has the weight on the media and all those things that are important. Second, if it is very big at the beginning there is the threat that it makes the actual work more difficult and more bureaucratic. If in every meeting there are representatives of twenty companies it quickly turns out that each of them has different interests and conflicting interests and so it's making the progress of the actual standard slower. The idea was that there had to be players from the different parts of the game so from the telecom and from the computing industry. And players which are strong enough that their market shares in their business area is big enough so that it has a real meaning when the standard is finalized."

Resource allocation not only requires developing a common understanding of what resources are needed but also must lead to the actors taking on roles and committing to contribute the required resources. This endeavor requires a negotiation process in which the resource requirements are matched not only with the resources and capabilities of the actors, but also with their preferences. In the Bluetooth case, for instance, Intel opted to act as the process facilitator due to its longstanding experience with de-facto standardization initiatives. In contrast, Ericsson was prominent during the market introduction phase as a result of the larger amount of available resources. To be able to proceed, the actors need to commit resources then decide if the outcome of the negotiation process is sufficient to proceed.

D-S-N are Recursively Organized. As noted above, D-S-N activities can be decomposed themselves recursively into sense-making, negotiation and design cycles. The practice of representing standardization processes as recursive processes allows us to scale our analysis using different levels of detail. While the overall design, sense-making, or negotiation cycle is simple in its structure, further breaking up the activities allows for the development of complex and fine-grained descriptions.

The recursive nature of design, sense-making, and negotiation can be seen in the following example from the NMT standardization. The NMT group was formed during a Nordic Teleconference held in June 1969 in Kabelvåg of Norway, during which time Sweden, without any prior notice, announced its intention to start developing a system for mobile services. This proposal was accepted during the same meeting as a Pan-Nordic initiative. The short initialization stage left many organizational and technical questions open. The primary goal of the group, according to the mandate, was not to design an integrated technical product, *but to create a common and compatible Nordic service*. Because of its broad scope, the service was open to negotiation for an extended period, while different alternatives for the service concept and its technical feasibility were designed and negotiated.

A critical issue in the service-related design was whether the system should be manual or automatic. To make the choice, several viable design alternatives had to be developed and subsequently negotiated among the participants. Developing these alternatives required sense-making of what manual or automatic systems would mean in terms of service, cost and technological implementation and its feasibility. Toivola (1992) recalls that although the starting point in the requirements was that the network should be automatic, the committee had to ensure that this option would be realistic. Designing an automatic system was not something taken for granted in the early 70s and estimating the costs associated with such a system was anything but straightforward. Both manual and automatic alternatives were designed while the actors derived probable system configurations and estimated their costs, finally choosing two alternatives that could be compared in terms of cost and technical requirements.

> "Six years after the original decision, the requirements were fixed when in its report in January 1975 the NMT work group analyzed the cost of both manual and automatic networks. A difference of SEK 3 million was found to favor of the automatic system. Ultimately, the choice [of automatic system] made by the NMT group shaped its success when it was introduced in the beginning of 1980s in that this choice proved was crucial for roaming." (Manninen et al. 2000)

The above vignette shows how within the design, sense-making, and negotiation cycle, the negotiation aspect can be broken down into another design, sense-making, and negotiation cycle (or two for each alternative).

Comparing D-S-N and Linear Standardization Models. Our suggestion that design, sense-making, and negotiation do not always unfold in a linear manner can be extended to standardization processes at large. Bluetooth provides an example of how at the first meeting of the core companies of the Bluetooth alliance, sense-making was occurring that affected the whole standardization process. In the meeting, managers created a common understanding of the cornerstones for process initiation, resource allocation and market introduction (see quotation on p.42), and concluded that, to achieve efficient development, a small group of standard sponsors would be ideal, but such sponsors should be from both the telecommunications and computer industries:

> "And we were looking for companies, which would hold enough market share in their business area that they could pull the market but that we could also survive with only these on board. We started from an assumption what if these are the only companies that are actually going to use it, is still so widely deployed that even these companies would make it successful on the market. When it is successful on the market then there are probably other companies joining the game."

This vignette shows how standardization can unfold in a non-linear fashion**.** It further shows that the processes of standards design and negotiation and the diffusion of artifacts based on those agreements are tightly interwoven and cannot (and should not) be separated in the analysis. Our cases suggest that the concept of separating design, sense-making and the negotiation of standards implicit in the normative standardization process does not reflect the actual standardization processes. Consequently, this makes them less useful in explaining why specific standardization processes succeed or fail. This is not to say that linear process models are useless, rather they are boundary objects used for sense-making and negotiating resource allocation and coordination tasks.

Discussion

A process theory of standardization, outlined above enables us to theorize over standardization processes and their outcomes. In the following, we shall pick up four issues related to standardization theory: 1) features of the proposed theory and its relationship to existing theoretical frameworks; 2) how this theory compares to current process accounts in standardization; 3) an analysis of the timing issues of standardization related to the theory; and 4) alternative uses of the D-S-N model in the study of standardization.

Nature of D-S-N theories

Process Theories

We believe that investigations that draw upon these notions help formulate empirical accounts that are more faithful to available empirical evidence and can provide more rigorous analyses of why and how emergent standardization processes come into being. They also provide a means of analyzing standardization episodes in a flexible and comprehensive manner, which helps cast our conceptual net widely and allows us to capture nuances of specific standardization episodes.

Theoretical formulations and models built upon these concepts can produce *process theories* (Mohr 1982; Markus and Robey 1988). These accounts are not state oriented variance theories, which are capable of defining necessary and sufficient reasons for Y to happen given X, i.e., X always precedes Y, or causes Y to happen. In such variance theories, it is also assumed that the outcome will invariably occur when the necessary conditions are present and sufficient. Such conditions are normally framed in terms of variables and dressed in an inference on the order of, if X then Y, if more X then more Y. Process theories, instead, analyze episodes of discrete events or outcomes $X_1, X_2, X_3,.. X_n$ in a manner, which shows that a string of specific set of events $X_2, X_3,.. X_n$ is necessary for a specific outcome Y_i, but that these conditions are not sufficient in that such outcomes may not occur given the sequence of events. Moreover, there can be other sets of events X_1, X_2, and X_3 that can yield the same outcome. For example, some wireless standards have become widely successful through very different configurations of events. There are some fundamental elements to all of them, such as changes in regulations systems (competition), the market focus in standard specification and service introduction and the timing of agreement with relation to technological development (not too early, not too late). Yet, no set of conditions can be said to be at the same time both necessary and sufficient to produce successful standards.

Another way to build process theories is to focus on the lack of specific events in specific episodes that do not result in Y_i. From this we can infer that if there is **not an** $X_2, X_3,.. X_n$ we will **not produce** Y_i. For example, a lack of market feedback and a purely technological focus (i.e. lack of sense-making or wrongly focused sense-making) in standardization processes have always resulted in standardization failures. Whereas the first group of process theories is mostly retrospective- they help explain why something occurred as it did, the second group will also allow for weak forms of prediction in the sense that we can, in most cases, exclude certain outcomes if certain conditions are not met. This, however, cannot be extended into a strong explanation in a form similar to, if X then Y or if more X then more Y. For example, more sense-making or more market focus will not necessarily lead to a successful standard. Hence, an important element in analyzing such event sequences is to identify random events and chance (serendipity), or a specific sequencing of events, which change the trajectory (Arthur 1989) of the process. Therefore, outcomes in such theories are predictable from the knowledge of processes, which are in our case framed as combinations and configurations of D, S, and N events over time.

A second type of analysis that can be carried out with the process models is to analyze what specific sets of events $\{X_2, X_3,.. X_n\}$, $\{X_1, X_2, X_3\}$ are likely to be associated with specific outcomes Y_i. For example, our analysis showed that the only sufficient condition for achieving a successful standardization outcome was to reach a closure in three activities: D, S, and N. Over time, these analyses can obtain patterns of configurations through identifying a common set of events $\{X_1, X_2\}$ that co-exist in sequences of events. A third type of analysis in which we can engage is to try to understand why X_n happened when X_k had happened before. This may expand the analysis to include descriptions of states and their configurations which explain *why* X_n happened instead of X_m after X_k had happened before. For example, both NMT, and GSM standardization processes were successful while some other standardization processes like CNET in Germany or PDC in Japan were not (Lyytinen and Fomin 2002). In all these cases a closure was achieved in D-activities (the systems worked and could be implemented), but these were associated with very different prior configurations of S and N activities due to institutional traditions and industry organizations. These different configurations lead over time to different standardization process outcomes.

Features of D-S-N Theories

In our view, a good standardization process theory should be able to explain *why* a specific outcome did emerge (success or failure) and why other alternatives were excluded. It enables us to compose a story about why acts, events and structure were organized in the way they were and how they co-produced the outcome. We can formulate our explanations with some level of causality in that we can argue what comes first, how it affects what will follow (Sutton and Staw 1995) and how timing will affect the process. The theory helps reveal underlying processes in order to explicate systematic reasons of why something did occur. As noted, we can also use it predict why something did not occur given the circumstances.

There is no best way to develop a theory. Its features depend on the nature of causality assumed, its scope and the specific goals of the researchers (Weick 1984). Consequently, theories differ significantly with respect to the dimensions of accuracy, generality, simplicity, explanatory power, and completeness. Here, there are important tradeoffs to make. As Weick (1984, p. 116) notes, no theory can meet all these criteria simultaneously: "General accurate theories are complex, general simple theories are inaccurate, and simple accurate theories have no generality."

We show how theories based on D-S-N constructs meet these criteria. As can be seen in the table, D-S-N based theories are quite distinct and complementary to the existing theoretical analyses of standardization. These theories usually aim to be general, complex and have varying modes of accuracy. Conversely, theoretical analyses derived from D-S-N seek to be accurate, scalable and operate with general and few concepts. They have low empirical generalizability and their additional downside is that they yield complex models and analyses due to their process and constructive nature. They offer answers to questions of "why" and "how."

Overall, we feel that the theory effectively meets the criteria for the specific theory choice in the context of developing process theories of standardization. We have traded generality against accuracy and simplicity in response to the need to understand and explain complex processes. In terms of theoretical orientation and the nature of organizing concepts, our theoretical position is closest to the position adopted in the social construction of the technologies research stream. In this regard, there is a deeper sense of theorizing. to which we aspire here, that we call *substantive* or *ontological* theorizing. Such modes of theorizing help us to understand the ingredients that make something possible or workable in the way that Simon's theory of decision making (Simon 1977) explains what makes decision-making possible. It has a rather small predictive capability, but carries strong normative implications of what one *should* not do.

Theory feature	***Description***	***D-S-N based theory***
Accuracy	The extent to which the theory describes in detail variations and specific features of the studied phenomena	Better than existing standardization theories. Helps formulate more detailed and close-up models of standardization processes and their outcomes[11].
Generality	The extent to which the theory applies to the whole population (Analytical generality). The extent to which the observations and findings are generalized over the whole sample of possible observations (Empirical generality).	Good analytical generality Weaker empirical generality due to small sample sizes and causality logic Enables scaling with complexity and yields higher degrees of generality with complex models (recursivity, hierarchical organization)
Simplicity	How many concepts and their relationships are embedded in the theory. Are these concepts distinct, well defined and intuitively clear?	Based on few simple concepts Organizing principles and relationships are complex and the main challenge is theory development Can yield complex theoretical models from these simple and few concepts[12] Challenge is to integrate good descriptive indicators and data points with each component The main components integrate and organize heterogeneous streams of theory and research
Explanatory power	Can the theory define necessary and sufficient conditions for something to happen (strong)? Can the theory identify sufficient conditions for something to happen (weak)?	Weak explanatory power Denies possibility for prediction in the strict sense (if A then B). A is only necessary for B to happen Enables explanatory accounts of why something happened when a set of events was identified Enables statistical generalizability over a set of process patterns, which lead to specific outcomes
Completeness	To what extent does the theory cover all necessary elements to explain why A was produced in all possible circumstances?	No clear criteria to judge completeness Institutions (stable configurations of actor networks) and power (the way in which actors can be influenced in the network) are implicit in the model.

Table 3. General Features of D-S-N Theories

[11] The model is in fact an outcome of the frustration we felt when trying existing standardization process models, which could not explain the phenomena we observed.
[12] This is in clear contrast to most existing standardization models, which yield relatively simple (linear) models out from several and complex concepts.

A Comparison with Current Accounts of Standardization Processes

As pointed out above, current standardization research separates standard design as the production of a technical specification, its choice as an economic or political game, and its diffusion in the market place as driven by economic or managerial prerogatives. These are treated as conceptually distinct, separate and necessarily distinguishable moments in the standardization. The basis of our theory denies the possibility of such separation for other than limited analytical purposes. Therefore, current theoretical analyses of standardization should also be more aware of the obvious limitations of this standing. Such separate analyses often ignore, in particular, the necessary sense-making related to both design and negotiation situations, which is largely driven by the actors' market perceptions. For example, AT&T (King and West 2002) failed to move successfully with wireless standardization and implementation despite its deep pockets and technological lead. This was caused by the fact that Ma Bell's management consistently perceived the market place through the lenses of universal (wireline) service that were driven by the need to sustain its monopoly rights. Despite this, its technology design (AMPS) was the most widely used 1st generation wireless standard and adopted by other aggressive entrants like McCaw.

Another issue in this study is to reveal the fragility of all three closures: design closure; significance closure; and negotiation closure. This fragility can be caused by a numerous factors and events that change designs, yield new interpretations, and transform interests and power balances. Because of this fragility, we face high rates of standardization failures and suffer crises in traditional standardization bodies that are not designed to address such levels of process complexity and uncertainty.

Timing of Standardization Processes

Several empirical studies of standardization episodes and processes suggest that the timing of events in reaching an agreement over the technical specification and the way in which this agreement is translated into a socio-technical network are of critical importance in the success of standardization (Haug 2002; Lyytinen and Fomin 2002; King and West 2002). Yet, most theoretical work on standardization research has not accounted for this observation. Economics and management literature has looked at standard choices from the viewpoint of a singular adopter and analyzed his or her welfare functions in light of network externalities. This approach largely ignores the actual processes of reaching an agreement (Farrell and Saloner 1986; David and Greenstein 1990). Likewise, most social construction of technology literature does not include the concepts that capture standardization processes as dynamic phenomena. Instead, it reduces processes to sense-making failures and identifies the specific qualities that influence the process outcomes (Williams and Edge 1996; Pinch and Bijker 1987). Finally, negotiation literature analyzes mostly static features such as the strength of the network, but pay only limited attention to the dynamics involved in creating the network. We believe that the D-S-N model more effectively highlights time related activities that build these socio-technical networks and leads to analysis of patterns of activities and their relationships.

The most interesting issue in time based analyses seems to be how time scales and events unfold along each set of activities and how they are co-related. Typical questions we could ask include the following: How and when do different and deviating meanings for technology begin to emerge? How and when do specific designs, technologies and architectures emerge, and how do they enroll specific technical communities? How and when do these become stabilized in designs that enter negotiations arenas and how do the socio-technical networks become stabilized? How are all these events synchronized, if at all? Though social construction of technology literature has analyzed many of these issues from a specific standpoint, it has not so far investigated the dynamics and time related aspects of the standardization. There is some analysis of critical events and time points when gatekeepers and their powers are highlighted (Latour 1995). These models are clearly still limited in outlining the dynamics of standardization. They ignore what actors actually know and how they make sense of the standards in specific time points in relation to markets or technological evolution. They also assume that actors know the other actors and their agendas. Our model suggests that such assumptions in most cases are untenable because sense-making is always frail. One way to address such issues is to ask the following: What are the limits of sense-making and is there some reasonable closure in a specific time frame with a given set of actors? How dynamic is the set of actors and can they agree on the standard due to differences in their cognitive framing and interests? What are their choice rationales and will they change or can they be negotiated during the process? This poses specific dilemmas for actors who are engaged in standard negotiation. When they enter the negotiation game too early it is easy to agree as the actors do not know to what they are agreeing. This may not necessarily be important, but it is difficult to make choices as technology does not make sense ; if actors enter too late it is easy to make sense but difficult to agree as the actors' agendas can vary, the technology is fixed and the sense-making has been closed. There are also different ways to affect the final design like influencing sense-making, influencing others' goals and utility functions or using power and increasing dependencies.

Future Applications of D-S-N Model to Analyze Standardization

The outlined standardization model above is not a governing law theory about standardization but suggests a narrative of standardizations (DiMaggio 1995). It neither explains nor excludes everything. Rather, it merely suggests a set of concepts and their relationships along with a set of analytical implications that we deem necessary and fruitful in theorizing about standardization processes. More specific standardization theories would imply a set of *specific types of* relationships between specific sets of D-, S-, N- configurations and specific outcomes. This may require refinement and expansion of concepts and a further formulation of specific constructs. At the same time, further theorizing requires the development of specific relationships between observed phenomena and their change. We see, however, that suggested concepts can serve multiple useful roles in developing such process theories.

First, they can be used to *develop more specific process analysis frameworks to analyze standardization processes as non-linear, emergent, and path-dependent processes*. Specific issues that can be addressed include the following: what types of non-linearity can be observed? Do the specific constellations of the activities refer to tipping effects as observed in organizational complexity theory (Axelrod and Cohen 2000)? How can these configurations be related to observed non-linear models in the innovation literature (Autio 1997)? What conditions and configurations standards create major deviations from existing dominant designs and create new forms of path dependency (Karnoe and Garud 2001)? How are paths and path creation activities reflected in process mappings? (These may first involve development of technical skills and solutions and related technical architectures and specifications as design path. Second they may entail invention, , transformation and sharing of cognitive schemata over time as a sense-making path, and third creation of of practices, histories and trust among set of standard adopters and producers as a negotiation path. Finally standardization implies development of "rules of the game" that govern how standards become "standards" on the institutional path.

Second, the *concepts can be used to formulate process theories that explain the failures or successes of standardization processes*. The concepts of D-S-N can be used to analyze specific standardization episodes. Researchers can pose the following questions: How did these activities become patterned and how do these patterns relate to standardization success or failure? This research would be similar to attempts to develop process theories of organizational change or IT implementation (Mohr 1982; Markus and Robey 1988).

Third, D-S-N concepts can be used to *understand, critique, and expand standardization process models from the view point of D-S-N closures*. Existing process accounts of standardization are both normative and linear. They are based either on product development models or regulation metaphors adopted from multilateral negotiations (Schmidt and Werle 1998). These models try to explain standardization as linear refinements over one dimension of the standardization process (design or negotiation) while ignoring the other two. We argue that such models are inadequate because they separate design (as covered by the product development part), negotiation (as governed by the regulation metaphors), and sense-making (which is currently neglected). If and when processes are nonlinear, all these elements should be accounted for to some extent in the process. To this end, the D-S-N model can be used to develop more contingency based process templates depending on the nature of D,S and N event configurations and the likelihood of failing in one or several of the standardization activities.

Fourth, using D-S-N concepts, we can develop *empirically grounded accounts of specific standardization processes that allow expanded theorizing.* Use of the D-S-N concepts enables researchers to formulate specific process theories from standardization data. For example, consortia based industries led standardization models like Bluetooth, 3G (3GPPP) or Java development may lead to different ways of configuring, orchestrating and organizing D, S, and N activities when compared with the traditional standardization processes followed in ITU or ISO (Schmidt and Werle 1998). There is also more emphasis on peer based specification and production modes (Benkler 2001) that negate the need to maintain intellectual property rights on the innovations and recognize them as part of the standardization process. To do this we must develop sharper constructs for identifying different types of D, S, and N activities and for distinguishing between specific institutional ways to organize and coordinate standardization. We must also develop categories that identify specific contingencies that influence the distribution and configuration of D, S, and N activities over a set of standardization processes. For example, it may be that D-, S-, N- activities have the same properties as Weick's (Weick 1984) theory properties. Standard setters cannot pursue them all at the same time and one of them may have to be sacrificed in the process of making a standard successful.

Conclusions

In this paper we have outlined a process theory of standardization. It draws upon and integrates several separate lines of inquiry into a dynamic analysis of standardization processes. It is not a theory, but a framework that enables theorizing over standardization processes in specific contexts. We demonstrate in the paper how it can be used to orchestrate empirical analyses of specific events during standardization processes. We provide evidence of the strength of D-S-N based analysis by analyzing vignettes of three complex standardization processes and by explaining their proceeding using the model.

We argue that D-S-N informed analyses and theories allow students of standardization to analyze a whole process of standardization as a sequence of events that carry forward acts of design, acts of interpretation and sense-making and episodes of negotiation and translation. All these events are recursively organized into a web of activities that span space and time. These concepts highlight the non-linear and complex nature of standardization, which has been neglected with past models of standardization. We demonstrate also the specific features of the theories that can be generated using the concepts related to D-S-N and compare them with the existing theories of standardization. The analysis shows that D-S-N theories trade off differently the requirements of generality, accuracy, simplicity and explanatory power.

The developed model invites new research on several fronts. First, we need to extend the analysis of activities to other standardization processes. Current analysis covered only fragments of situations in telecom and wireless standardization. Obvious targets for empirical validation are standardization processes outside official standardization bodies (e.g. Java) and emerging interoperability standards in IT (like XML, EbXML). These processes may indicate specific traits of D-, S- or N activities and their organization that are not present in studied telecommunication standards. The work could also be used to understand complex infrastructure development in general (see Bergman, King, and Lyytinen in press). There are several specific topics in standardization that can be attacked by this line of inquiry including timing and dynamical issues, more specific process analysis frameworks for specific standardization arenas. In the future we need to focus on analyzing more detailed process patterns in typical standardization situations and expand that to a set of standardization processes to analyze variance. More work is required in order to integrate institutional aspects into standardization process analysis.

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Appendix 1: Case Overviews

Our first case is the Nordic Mobile Telephone (NMT) system. The case of the NMT standard is an excellent example of a successful standard-making process (Fomin and Lyytinen 2000). There are several reasons why it is an interesting case for analysis. First, it was created at the time when there was a market demand for this kind of technology, but the needed technology was not yet available (Toivola 1992). Second, it was developed almost at the same time as another major cellular telephony standard, namely AMPS[13] in the US, but witnessed much greater acceptance and success (West 2000). The developers of the NMT system gambled on the rapid advance of radio and micro-electronic technology and designed the system "for the future". They ignored the fear of a high level of uncertainty due to their ability to anticipate in 1969 that what national PTTs[14] had was *"really a technology for the 60s, and that wouldn't do it for the 1970s"* (Manninen and Fomin 1999). This move necessitated the PTTs to create close relationships with otherwise external producers of telephone, radio, and micro-electronics equipment. We believe there were important social and cultural implications in the standard settings, which facilitated the standard creation process and paved the way for the standard to be delivered to the market.

The second case, the GSM cellular telephony system, is interesting because of the European PTTs' political interests and ambitious aims in the standardization process. Many European PTTs shared an opinion already in 1980 that each European country would benefit from an introduction of a pan-European system (Bekkers and Smits 1998; Meurling and Jeans 1994; Toivola 1992). Non-official discussions in Paris in 1980 revealed that CEPT[15] would be too cumbersome to lead the standardization work (Manninen et al. 2000; Toivola 1992). This resulted in establishing Groupe Spécial Mobile (GSM), a body subordinated to Committee for Coordination and Harmonization (CCH) of CEPT. The goal of GSM group was to harmonize technical and operational specifications for a public mobile system on the 900MHz frequency (Toivola 1992). The creation of GSM ended the European fragmentation in the mobile telephony and became a leading wireless standard (Mouly and Pautet 1992). Yet, before this was achieved, many technical, economical and political challenges had to be resolved.

The third case involves standardization of short-range radio technology called Bluetooth[16]. Already in the early 1990s, several electronics, information technology and telecommunications firms explored possibilities of connecting devices such as mobile phones, laptops and peripherals without wires. Several technological alternatives were developed to address this challenge. In 1993, IrDA[17] was formed to create an infrared data interconnection standard. Primarily, companies from the computing and semiconductor industry sponsored this standard. At the same time several portable computer manufacturers experimented with radio technology to address the problem that infrared technology required a line of sight between devices. Yet, to make it widely applicable all manufacturers would have to conform to this standard. Therefore, in 1997, five companies announced a consortium to develop and promote an industry standard that would use radio technology. The consortium was organized so that these

[13] AMPS – Advanced Mobile Phone System.
[14] PTT – Post Telephone Telegraph, usually a state owned monopoly organization providing these service
[15] CEPT – (Fr.) Conférence des Administrations Européenes des Postes et Télécommunications
[16] See http://www.bluetooth.com
[17] IrDA – The Infrared Data Association.

five companies would develop the standard while other companies were allowed to join the consortium as adopters without any direct influence on the specifications. The initiative has been successful in that over 200 firms have committed themselves as adopters to the specification when version 1.0 was released in September 1999.

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