Institutional entrepreneurship in technology standards evolution:
The case of Ethernet

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ABSTRACT
Technology standards refer to the specifications that provide users and vendors with a common platform and ensure seamless integration between components of a technological system. Prior literature has largely focused on examining the processes by which such standards emerge and has suggested that once they do so they typically constrain agency on the part of actors. In this paper, we ask the question: how do technology standards evolve? Through an in-depth historical analysis of the Ethernet LAN (local area network) standard we inductively develop a model identifies three key sub-processes associated with technology standards evolution – extension generation, ratification and incorporation. By continually engaging in these processes, actors can dramatically increase the functionality of an existing standard and in certain instances enable it to evolve along trajectories not originally envisioned. This can significantly boost the standard’s competitive viability. In elaborating these dynamics, we emphasize a more active conceptualization of standards persistence that requires examining the ongoing interplay taking place between actors and the rules they create.

Keywords: Technology standards, extension development, institutional entrepreneurship
INTRODUCTION

Technological systems consist of a number of components that interact with one another in combination provide utility to customers. The functionality of such systems is dependent not only on the performance of the constituent components but also on the extent to which they are compatible with each other (Henderson and Clark, 1990; Sanchez, 1995; Schilling, 2000). Technology standards in this context refer to the interface specifications or “rules of engagement” that provide vendors and users with a common platform and ensure seamless integration between components of a technological system. The WINTEL platform in personal computers, the VHS format in the videocassette recorder market and the CDMA and GSM protocols in wireless telephony are just some examples of the pervasive presence of standards in information technology (IT) based fields.

The emergence of technology standards represents a pivotal point in the evolution of a field (Tushman and Anderson, 1986; Van de Ven and Garud, 1989). Their emergence reduces uncertainty by providing vendors and users with a stable developmental platform that is essential for widespread diffusion of a technology (Rosenberg, 1976). Moreover, their presence significantly lowers manufacturing costs insofar as vendors achieve economies of scale through the supply of mass-produced components. In addition, they foster complementary innovations and product refinement and thereby afford opportunities to take advantage of learning effects and technological spillovers in the development and production of specific components (Katz and Shapiro, 1985; Farrell and Saloner, 1986). Their presence allows an emerging field to acquire momentum with significant organizational resources now vested in the technological
trajectory associated with the standard (Dosi, 1982; Hughes, 1983).

Given their significance, there has been a large amount of research devoted to how these technology standards emerge (David & Greenstein, 1990; Tushman & Rosenkopf, 1992). The economics of standardization literature has extensively examined the emergence of these rules through market processes. This typically involves engaging in strategies geared towards establishing a large installed base of users (Katz & Shapiro, 1994). The sociology of technology literature emphasizes the role played by actors such as vendors, users, industry committees and government in shaping technology standards (Noble, 1984; Gabel, 1987; Frost & Egri, 1991). From this perspective, these rules emerge through a negotiated socio-political process enlivened by actors with divergent interests (Garud & Rappa, 1994). Both literatures then highlight the significance of institutional entrepreneurship on the part of actors in shaping technical standards that in turn structure the field.

By contrast, there is relatively little work that explicates the mechanisms by which technology standards evolve. Rather, extant models of technological change suggest that the presence of technology standards comes at a price, typically constraining future development of a technology to particular trajectories (Dosi, 1982). Technological progress, at this stage, takes on an incremental nature, and is driven by the invisible hand of a multitude of organizations competing within sharp technical, social and normative constraints (Tushman and Rosenkopf, 1992). The path dependence and cumulativeness implicit in such a progression can “lock in” consumers and vendors, and at the extreme, can prevent a technology from evolving to higher levels of functionality – the QWERTY design of the typewriter keyboard being the most prominent example offered in this
regard (David, 1985; Arthur, 1989). Put differently, once a set of technological standards is in place, they embody sunk costs – both economic and psychological – that are difficult to recover (Powell, 1991). Over time, change in technology standards takes place through a process of substitution with a new standard that ostensibly represents a higher level of functionality replacing the earlier one.

This imagery of technology standards evolution, however, does not square well with the empirical reality observed within many IT-based fields. There are numerous examples that suggest that interface specifications undergo a process of continual change and updating within these fields. As a computer networking expert put it, “The speed of compatibility standards change reflects the speed of change in the technology; in an industry where ‘normal speed’ goes from 9600 bps to 45 Mbit/sec within 5 years, you can’t expect the standards to remain constant” (Alvestrand, 1995). Or as a vendor commented, only partly in jest, "If you don’t like standards now just wait a few years and they'll change" (Data Communications, 1982a). Yet research to date has revealed very little about the nature of agency involved in the evolution of such rules. The research reported in this paper intends to address this gap in the literature by inductively developing a process model that explicates the drivers of technology standard evolution.

In this theory extending study, we ask the question: how do technology standards evolve? We conduct an in-depth historical analysis of the Ethernet LAN (local area network) standard to inductively develop a model that explicates these dynamics. This model identifies three key sub-processes associated with technology standards evolution – extension generation, ratification and incorporation. By continually engaging in these processes, actors can dramatically increase the functionality of an existing standard and
in certain instances enable it to evolve along trajectories not originally envisioned. This can significantly boost the standard’s competitive viability. In elaborating these dynamics, we emphasize a more active conceptualization of standards persistence that reveals the ongoing acts of institutional entrepreneurship that actors engage in.

THEORETICAL BACKGROUND

In this paper, we elaborate on a perspective which suggests that technology standards are a key facet of the institutional space associated with technological fields (Scott, 2001; Garud, Jain and KumaraSwamy, 2002; Wade, Swaminathan & Dowell, 2002). Put differently, they are akin to institutional rules that reduce uncertainty and govern patterns of expectations and interactions among the various members of a field (North, 1990). They do this by providing the underlying framework and meaning structure within which product markets associated with the field operate (Aldrich and Fiol, 1994; Dobbin and Dowd, 1997; Ventresca and Porac, 2004).

While much of the literature has focused on the emergence of technology standards through market forces, increasingly, rule setting is taking place within venues expressly established to develop such specifications (Cargill, 1996). These forums of collective action typically comprise of members from different organizations including the government, vendors, end-users and academia. There has been a dramatic growth in such institutions over the past decade with over 550 groups devoted to standards creation (Cargill, 1996). Some of the more prominent venues for technology standard setting include the IEEE (Institute of Electrical & Electronics Engineers), the ISO (International Organization of Standardization), the ITU (International Telecommunications Union) and the W3C (World Wide Web Consortium). In this paper, we shall focus on the
development of collective technology standards within such forums.

In order to appreciate the relationship that exists between technology standards and actors belonging to a field, it is useful to examine this linkage within the context of existing models of technological change. During the early stages of this cycle, the absence of standards results in actors placing bets on different technologies based on their beliefs of what will be possible in the future (Garud and Rappa, 1994). This leads to substantial rivalry between competing factions to establish their technology as the standard (Tushman and Rosenkopf, 1992). The lack of standards however, also results in high levels of ambiguity about which of these technologies will eventually become dominant. Confronting ambiguity, component manufacturers might not make the requisite investments and customers are likely to postpone the purchase of specific products thereby dampening development of the field (Rosenberg, 1982).

Over time, through a process that often involves intense socio-political dynamics, the number of competing technologies is winnowed down and a single technology standard emerges (Van de Ven and Garud, 1989; Tushman and Rosenkopf, 1992). The emergence of such institutional rules enables the field by reducing user uncertainty and creating stable expectations between mutually interdependent actors. Such stable expectations are important for fostering innovation in complementary parts of the technological system. As firms innovate to the common standard, benefits from supply and demand side externalities begin to accrue (Katz and Shapiro, 1985; Farrell and Saloner, 1986, Economides, 1996).

While the emergence of technology standards enables activity among actors belonging to a field, they circumscribe the basis for action and constrain the behavior of
actors along particular trajectories (Dosi, 1982). Along these lines, various strands of the technological change literature highlight the stability of standards (or a dominant design, as they are often referred to) and emphasize the onset of a different phase in a technology’s development once they emerge. Utterback & Abernathy (1975) suggest that the surfacing of a standard marks the transition of the field from a fluid to a specific state and involves a change in emphasis from product to process innovation. Product variety is reduced, with change taking place through differentiation in terms of minor design variations and strategic positioning tactics. The focus of competition largely shifts from higher performance to lower cost with efficiency and economies of scale being emphasized in production.

At a cognitive level, the emergence of technology standards indicates that critical dimensions of merit have been defined and settled. Further technological progress likely involves routinized puzzle-solving about an established set of technological premises and the emergence of social structures that reinforce the existing technological mindset (Sahal, 1981; Tushman and Rosenkopf, 1992). Nelson & Winter (1982) use the term natural trajectories of technical progress to indicate that once a path has been selected, it possesses a momentum of its own that is very much constrained and directed by the cognitive framework that actors within the field bring to the development situation. Indeed, technological paradigms engendered by these rules have a powerful exclusionary effect – they focus the imagination and the efforts of actors as well as the organizations they work for in rather precise directions while making them “blind” with respect to other technological possibilities (Dosi, 1982).
A similar theme can be found within the institutional theory literature, which extols the benefits that actors derive by conforming to existing institutional rules and suggests that once such rules emerge, any alteration of these arrangements involves high switching costs, with a host of political, financial and cognitive considerations mitigating the making of any changes (Powell, 1991). As a consequence, the constraints imposed by an institutional rule can ensure its persistence long after the arrangement is viewed as being not necessarily optimal (North, 1990; Powell, 1991). This suggests that like other types of institutional arrangements, technology standards, once they emerge, have powerful constraining effects on the behavior of actors due to presence of sunk costs, learning effects and coordination costs (Arthur, 1989). At the extreme, they exhibit strong path dependent tendencies in that the trajectories related to them do not evolve beyond limitations imposed by the original specification – i.e., actors remain inert and “locked-in” within the original standard (David, 1985; Arthur, 1989).

Above, we have provided various mechanisms identified in the literature which suggest that once technology standards emerge, they tend to significantly constrain the actors that constituted them to innovating within specific trajectories defined by the original rule. In these literatures, technology standards are conceptualized as being largely static and “taken for granted”. Changes made to the standard are incremental in nature in that they represent minor variations on the existing rule that reinforce the established technical order. Often such changes are observed as taking place at the subsystems and the linking innovations level – i.e., at a lower level of design hierarchy (Clark & Abernathy, 1985; Khanna & Iansiti, 1995; Tushman & Murmann, 1998). More importantly, the underlying mechanisms by which such incremental changes in the rules
takes place is rarely explicated – the closest explanation provided is that such changes follow a pre-determined technical and economic logic (Tushman & Rosenkopf, 1992). To the extent that technology standards substantially change in such scenarios, it is through a process of displacement precipitated by discontinuous technological change that ushers in a new (and presumably, higher functionality) technological standard which replaces the extant one (Anderson and Tushman, 1990; Shapiro and Varian, 1998). The evolution of a number of technology standards – for example, the transition from LP’s to CD’s in the recorded music field and that of VCR’s to DVD’s in the video player industry can be seen as examples following this pattern of standards evolution.

However, this theory of technology standards evolution does not appear to adequately explain dynamics that are unfolding within numerous IT-based fields. As indicated earlier, in these fields technology standards appear to be in a state of continual flux (Brown & Eisenhardt, 1997). As Bill Joy of Sun Microsystems explained:

> We have something that economists find truly amazing which I certainly didn't appreciate. We all know that committees take a long time to make standards, and it also appeared, say ten years ago, that the marketplace took a long time, "because everybody just sort of dug in their heels". What we have now is this kind of funny interplay between committees and the marketplace, each trying to outdo the other to set standards, thereby driving the industry forward far more quickly than the other would have done by itself. This is a truly amazing phenomenon.

Given this scenario, there is need to inductively develop theory that explicates the processes underlying technology standard evolution in these fields. In this paper we address this task by carrying out a historical analysis of the Ethernet standard that explicitly examines the development of extensions to this specification. In doing so, we identify three key sub-processes associated with technology standards evolution –
extension generation, ratification and incorporation. Cumulatively, the development of extensions can dramatically increase the functionality of the standard and in certain instances allows it to evolve along trajectories not originally envisioned. Moreover, such extensions can ensure the persistence of a technology standard and result in the demise of competing alternatives. Overall, our process model highlights the ongoing interplay between members of a field and the collective rules they create (Giddens, 1984; North, 1990; Barley and Tolbert, 1997).

RESEARCH DESIGN

The nature of the research question outlined suggested the use of qualitative methods to examine the phenomenon under study (Yin, 1994). In particular, our research strategy focussed on elaborating the sequence of events that related to the emergence and evolution of a specific compatibility standard. The intent was to cut deeply into the specifics of a time and place and trace the processes that generated the outcome of interest (Bates et al., 1998). Adopting such a research strategy enabled us to explicate the underlying drivers of compatibility standards evolution.

Sampling in theory building studies relies on choosing “strategic research sites” (Bijker, Hughes and Pinch, 1987) that capture the integral aspects of the theoretical phenomena under examination. In conducting these studies, care needs to be taken to ensure that the findings are generalized in an analytical rather than statistical sense to similar contexts (Glaser and Strauss, 1967, Eisenhardt, 1989). The research site that we chose for this study was the Ethernet standard within the LAN field. A LAN refers to the information grid that connects personal computers, printers, servers and other devices within the same building and enables them to communicate with one another. Given the
systemic nature of LANs, technology standards are a critical component to the unfolding of activity within this field. Moreover, the LAN field has been associated with rapid technological change ever since it gained prominence in the early 1980’s. Finally, the Ethernet specification has had a long history associated with it that allows one to make meaningful generalizations about the evolution of technology standards from this context to a number of other rapidly evolving IT-based fields.

The next step in the research process involved constructing a timeline of events that described the emergence and evolution of the Ethernet standard over a time period of 32 years beginning from its invention in 1973. This involved integrating data from different sources using multiple methods in order to increase the reliability and the validity of the findings (Jick, 1979). The primary sources of information included archival data and field interviews. We first accessed articles appearing in trade journals and the business press on Ethernet over the prescribed time period. A key reason for employing this approach was to provide a contemporaneous feel for the phenomena – i.e., describe events in terms of the context that the actors faced at the point in time at which the articles were published. This, in turn, reduced the likelihood of retrospective bias. Moreover, analysis based on these articles was more open to scrutiny, as the “raw data” was accessible in the public domain (Ross and Staw, 1993).

We began this search process by using the Computer Database (#275) within DIALOG (an on-line retrieval service) to retrieve abstracts of articles on Ethernet. This database is acknowledged for its comprehensive coverage of the IT sector and contains articles from over 110 widely circulated journals and magazines on computers, telecommunications and electronics. In total, our initial search identified over 15000
entries for the time period involved. After reviewing all the abstracts, the focus in data
collection shifted to obtaining more in-depth information on the specific events
mentioned in these abstracts. This was accomplished in two ways: (a) obtaining full-text
versions of the relevant abstracts, either through online sources or via microfiche, and (b)
consulting other archival data sources on the LAN field. Specifically, we referred to a
number of academic articles (Sirbu and Hughes, 1986, Lehr, 1992; Kenney and Von
Burg, 1999) and books written by industry experts (Tannenbaum, 1988; Johnson, 1995;
Seifert, 1998) that provided details on the history of the Ethernet standard. In addition,
we read books written by industry experts in the field (Cargill, 1989; Libicki, 1995) as
well as reviewed all the issues of a professional journal (Standardview) that appeared
from 1993-1998 to further augment our understanding of the standardization process in
the IT sector.

The Institute of Electronic Engineers (IEEE) is the professional organization
within which multiple LAN standards (including Ethernet) are formally specified. We
attended the IEEE LAN committee plenary meeting held in July 1998 in order to get a
first-hand understanding of the process by which specifications for Ethernet were
established within its designated committee. At the meeting, we conducted semi-
structured interviews with 18 individuals who were pivotally involved in establishing the
specification. These interviews ranged in length from 30 minutes to 2 hours. After the
meeting, we sent transcripts of these interviews as well as a set of follow-up questions to
our interviewees. They all responded to these queries via e-mail. In addition, we also
reviewed standards documents and minutes of meeting data associated with the Ethernet
committee to gain a more intimate understanding of the standardization process. Data
from the interviews was recorded separately and used in conjunction with the archival information to sharpen theory development.

Poole et al. (2000) suggest that “In order to address the ‘how’ question, one requires a story that narrates the sequence of events that unfold over time”. In preserving chronological flow, such a narrative enables the researcher to gain a better grasp of which events and processes led to consequences, enabling him/her to make stronger statements about causality. Proceeding from this principle, we constructed a detailed timeline of events from the sources mentioned above. The timeline was then employed to develop a qualitative account that described the flow of events fundamental to the emergence and evolution of the Ethernet standard. In order to establish its validity, the account was distributed to industry specialists to verify its accuracy.

In developing the historical narrative, we remained cognizant of the theoretical issues and constructs that emanated from the data. These themes in turn guided further data collection. This process of iteration between theory and data continued until the emerging theoretical account adequately captured the narrative and latent generative mechanisms were identified and specified (Drazin and Sandelands, 1992). This was equivalent to achieving “theoretical saturation” (Glaser and Strauss, 1967), with the refined narrative forming the basis of exposition of the theoretical account. Put differently, the analysis at this stage involved converting descriptive historical accounts into analytical ones that were couched in theoretically relevant language (Bates et al., 1998). As a final step, the emerging theoretical insights were compared with the existing literature. This process of comparison enabled us to identify similarities and highlight differences between the theoretical account resulting from my research and the extant
literature. This process of theory extending, then, is akin to climbing the “ladder of analytical abstraction” (Carney, 1990). We begin our analysis by providing an historical account of the emergence and evolution of the Ethernet standard. See Table 1 for a description of the entire sequence of steps that we followed to carry out this study.

Insert Table 1 around here

THE UNEXPECTED PERSISTENCE OF ETHERNET

Starting in the late 1970’s, the proliferation of personal computers and workstations in offices led to a giant step in the evolution of office automation. Even as these personal productivity tools began to populate the desks of individuals, efforts were underway to link them together to form LANs that provided users with high-speed data transfer between workstations and access to shared resources such as laser printers. These attempts, however, ran into a unique problem – that of communication. Given its high-growth potential, a large number of actors – both established firms and start-ups – began to enter this emerging field around this time with proprietary product offerings. To avoid a veritable Babel among the myriad devices built by different manufacturers, rules that specified precisely how these devices would communicate with one another over the network were required. Indeed, such standards were seen as crucial to facilitating the emergence of the LAN field (see Table 2 for a chronology of events associated with the LAN field).

Insert Table 2 around here
Establishing Ethernet as a collective standard

The origins of collective standards within networking fields dates back to the early 1970’s when the Institute of Electrical and Electronics Engineers (IEEE), a premier standards organization, created the IEEE 488 standard that was designed to connect programmable instruments so that they could be controlled remotely (Von Burg, 2001). Given this early success, it was not surprising that actors within the nascent field turned to the IEEE to establish a standard for LAN’s. In mid-1979, Maris Graube, an engineer with Tektronix submitted a project authorization request (PAR) which was necessary to initiate such an effort. A mandate to research and formulate standards for LANs operating at up to 20 Mbps (million bits per second) was subsequently created. The project was named 802 for the year (1980) and month (February) that it was officially formed in. The standards initiative attracted much interest with a large number of individuals (approximately 75) - representing a diverse set of vendors - attending the first meeting.

Project 802 was a unique standards-making initiative in certain ways. Most significantly, it was an attempt at establishing a standard in advance of the market – i.e., it was an “anticipatory standard” (Cargill, 1989; Weiss, 1989). An anticipatory standard aims at providing the various constituents of an emerging field with an institutional framework that facilitates adoption of the nascent technology and enables the formation of product-markets. In such cases, there is tacit recognition among the actors involved that the emergence of a mass market associated with a novel technology is predicated on the establishment of a prior set of rules. Rather than allow those rules to emerge largely from marketplace dynamics, actor define them through their interactions within an institutional forum. Until that point, standards development organizations had mainly
been involved in ratifying market standards that had already been established (Weiss & Sirbu, 1989).

The above description should also make it abundantly clear that establishing collective standards that are anticipatory in nature is likely to be a risky and contentious. This is because the multiple actors that participate in the process each have a different conception of what the specification should incorporate. Often, these actors have invested in their own technology development programs and have a strong incentive to push standards development in their direction. Doing so enables them to incorporate attributes of their technologies directly into the emerging institutional rule (Meyer and Rowan, 1977; Constant, 1980). This suggests that the creation of collective standards within institutional forums is an intensely socio-political process with the emergent rule being forged through a negotiated logic.

Soon after the IEEE set up Project 802, actors began to offer specifications that they had been previously working on for ratification by the committee. One prominent player on this front was the DIX (Digital-Intel-Xerox) alliance. This group had formed in late 1979 to pool efforts and jointly develop a version of Ethernet -- a LAN technology developed at Xerox’s Palo Alto Research Center (PARC) earlier in the decade -- that was implementable in silicon and suitable for manufacture by a wide variety of companies (Seifert, 1991). At the May 1980 meetings, the DIX alliance indicated that it was willing to work with the IEEE committee by offering the Ethernet specification to them for formal ratification. The group also liberally licensed the specification to a number of vendors after publishing the completed version of it in September 1980. For the DIX alliance, the choice of creating an open specification was a deliberate one given that it did
not jeopardize their core businesses, made it more attractive to customers and enabled it to attract a large number of third-party suppliers. Given these motivations, obtaining the endorsement of an official institutional forum represented an additional means by which they could increase support for their specification. As Bob Metcalfe, the inventor of Ethernet elaborated:

“The old strategy of get to them firstest with the mostest? That's a viable way to proceed in a static marketplace, where there are only so many customers. But in this business there are other, more meaningful ways, such as the endorsement of the Institute of Electrical and Electronics Engineers… While these groups don't have the power to say, yes, Ethernet is now the official standard, they do greatly influence purchase decisions in large corporations” (Frazier, 1984).

Formal standardization of a LAN specification within the IEEE, however, turned out to be a much more convoluted task. While the DIX alliance suggested that they were willing to work with the committee, they also indicated that they would go ahead with development of their specification even if the committee did not consider it. This behavior did not endear them to the members of the committee who saw the alliance as attempting to manipulate the formal negotiation process by placing them in a position of merely ratifying the DIX’s group’s technology (Sirbu and Hughes, 1986). Moreover, as details of the Ethernet specification emerged, some IEEE members expressed their reservations relating to the technical merits of the protocol. In particular, Ethernet was perceived to be unsuitable for factory environments because it did not provide deterministic access which they believed was critical for real-time processes.1 By this time, it was clear that there were two distinct groups within the 802 committee: the supporters of Ethernet

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1 Deterministic access guarantees that a device will gain access to the network within a prescribed period of time. CSMA/CD networks (of which Ethernet is an example) cannot make that guarantee because there is a statistical probability of successive collisions delaying access to the network.
and CSMA/CD (the “office-automation” people), and the supporters of token passing (the “factory automation” people).\textsuperscript{2} Anticipating this stalemate, members of the committee voted to develop two standards.

Moreover, as the CSMA/CD standardization initiative unfolded, both the IEEE and the non-DIX companies participating in the effort attempted to establish an identity for the emerging 802 standard that was unique from the original DIX specification (Batt, 1982; Graube, 1982).

It was not till June 1983 that the committee ratified the standard that, from a technical viewpoint, was virtually similar to the original specification that had been submitted by the DIX alliance. In terms of its key elements, the standard consisted of the following elements – a network speed of 10Mbps, coaxial cable as the transmission medium, a bus topology, a baseband signal, a shared media access mechanism known as CSMA/CD and a maximum segment distance between 2 nodes of 500m. This specification was formally referred to as 10Base5 and known by vendors as Thick Ethernet. In combination, these various elements defined the technological trajectory related to the original Ethernet standard.

**Impacts of collective standard**

Traditional theories of technological change suggest that the emergence of a standard is followed by a period of incremental change during which attention within the field converges towards cost reduction and process improvement activities. Over time, constraints begin to be identified and eventually the standard is replaced by a new one.

\textsuperscript{2} CSMA/CD and Token Passing refer to medium access techniques. Ethernet was based on the CSMA/CD scheme while proponents of factory LAN automation favored a token passing scheme, though a specific specification did not exist at that point.
With its endorsement as a formal specification and a large number of vendors licensing the specification (over 200 by 1983), Ethernet soon began to dominate the fledgling LAN field. As Bill Carrico, President of Bridge Communications put it, “Ethernet is the only thing out there that is shippable by anybody that is a standard product. That is really the bottom line” (Semilof, 1984). Even as the number of Ethernet installations began to grow, a number of competing proprietary LAN alternatives started to wither away. This period was also witness to significant process and manufacturing innovations that significantly reduced the cost of Ethernet installations. While the of an Ethernet card and associated cabling was about $5,000 in 1981 (Data Communications, 1982b), the arrival of standardized chips manufactured by Intel and AMD after ratification of the specification brought costs down to $500 per node by late 1984 (Semilof, 1984).

Even as the Ethernet standard became dominant within the nascent LAN field, a number of constraints began to be identified with implementations of the specification. First, the coaxial cable on which the standard was based was prohibitively expensive for connecting the growing installed base of personal computers. Even with the dramatic price reductions that had been achieved, Ethernet was still perceived as a high-end LAN. Moreover, the cable was notoriously difficult to mount because of its thickness and required specialized equipment and labor for office installation. Finally, the method by which nodes were connected to the cable was highly cumbersome and prone to failure. Besides the use of coaxial cable, a second significant limitation of the Ethernet specification was that it was based on a bus topology, which comprised a single data path to which all equipment was directly attached, and upon which all transmissions took
place. In the early 1980’s, networks were relatively small and did not require much network management. But gradually as the number of nodes on a network increased, the lack of a central point of connection became a serious handicap as dysfunction in one node on the bus caused the entire network to fail and made troubleshooting a nightmare. And finally, a limitation that became salient only after the endorsement of the original Ethernet specification was the lack of a version of the standard that could operate on telephone wiring. The need for such a standard was evident given the widespread adoption of structured telephone wiring systems in office buildings during the mid-1980’s. As a consequence, users were reluctant to make significant investments in a separate cabling system for their LAN’s. This limitation became particularly significant when IBM officially launched its own LAN specification, called Token-Ring, in October 1985 that worked on telephone wiring.

The description above is indicative of the various limitations that come to be associated with a standard once it is established. Given limited upfront exposure in the field, it is entirely possible that a number of shortcomings are identified with the specification once implemented. In this particular instance, cost, ease of usage and the inability to function in certain environments all represented limitations now associated with the original specification. These can be further exacerbated by the availability of alternate standards that specifically address some of these constraints. Such developments can seriously curtail the time frame for which a standard is viable. This was a dynamic not lost on the original members of the Ethernet standardization effort, one of whom said

“When designing Ethernet, we used a 20-year product cycle as our model, expecting that installations and quantities would ramp up over the first five to ten years and then taper off as middle age set in and some new technology emerged” (Seifert, 1991).
Now it appeared as if Ethernet’s viability would last only until the early 1990’s. The question that loomed for the actors associated with the specification was – in what manner would they respond to the identified limitations in the standard?

**Extension development on the original specification**

According to the technology life-cycle model, after a standard has emerged, agency on the part of the actors that constitute the field is significantly restricted and is limited to making incremental changes to the existing specification. By contrast, what has been remarkable about the actors associated with the Ethernet standard has been their ability to engage in significant acts of agency even after the initial standard was established. They have done so primarily through the creation of extensions to the original specification. During the period 1985-1990, the IEEE committee ratified five extensions to the original standard. Cumulatively, these extensions addressed all of the constraints that had been identified with the original standard. Even more surprisingly, these extensions enabled Ethernet to evolve along directions that had not been envisaged by its original developers. From a competitive viewpoint, these extensions have enabled Ethernet to remain the dominant LAN standard and ensured the demise of various competing alternatives including Token Ring and FDDI. Given the significant role that extension development has played in the persistence and competitive success of the Ethernet specification, the question then arises: what underlying acts of agency contributed to the processes fostering the development of these extensions?

**Extension generation**

Part of the flurry of standardization activity even after the ratification of the original specification can be attributed to the anticipatory nature of the collective
standard. While actors try and ensure that that the ratified specification incorporates future needs, the fact is that such standards do not have much prior exposure in the market (Cargill, 1989; Weiss, 1989). As cumulative customer experience with implementations of the standard begin to grow, it is likely that vendors identify variations on the original specification that are likely to appeal to specific user segments. These variations form the basis of a new set of proposals that are brought to the standards committee for potential ratification. Put differently, limitations identified in the original specification often serve as a spur, rather than a constraint, to agency among members of the field in the form of extension development (see also Hughes, 1983 for a discussion of “reverse salients” associated with technological systems). On this front, there may in fact be some benefits to incompleteness in the original specification, as this would enable actors to build relevant extensions to the standard as the field evolves and various uncertainties associated with it (user needs, competitor actions, etc) resolve themselves.

This dynamic manifested itself in terms of multiple different flavors of the Ethernet specification that were under consideration by the IEEE within a year of the original standard being ratified. The actors associated with developing and ratifying the initial Ethernet specification within the committee had traded technological complexity for (relatively) speedy market introduction. Even as limitations in this standard began to be articulated in the field, extensions to the specification began to be proposed within the committee. Donald Loughry, head of the committee and an engineer with Hewlett Packard, had this to say about the proliferation of proposals, “There’s a good reason for each of the new standard proposals to exist. Each addresses a different geographical scope, traffic type and topology” (Mier, 1984). This has been followed by a continual
flow of extension generation that continues to this day. Many of these extensions were proposed by a different set of actors indicating that the locus of innovation had now moved beyond the original proponents of the specification (i.e., the DIX alliance). On this front, the historically open nature of the standard facilitated the entry of a number of start-ups into the field that became the source of a number of the key extensions generated on this specification. These start-ups then played a significant role in infusing imaginative ideas that enabled the Ethernet community to address limitations associated with the extant standard.

At an underlying cognitive level, extension generation is a function of the degree to which members within the field interpret the existing specification as being mutable. The collective nature of the standard setting effort suggests that the multiple actors are likely to have varying rationales for proposing extensions to the specification. Actors then need to provide other members of the field with technical and market-based justifications for developing these extensions. This in turn requires determining which aspects of the standard are immutable and which can potentially be modified and more importantly, establishing a collective consensus with other members of the field as to the mutability of the existing standard. Given this set of dynamics, there is often significant variation in the extent to which a standard is viewed as being mutable by actors within different fields – that ranges from more flexible to more rigid – that in turn determine the level of extension development on a standard.

These dynamics were particularly evident in the development of the extension known as telephone-wire Ethernet (10BaseT). In early 1987, AT&T announced that it had signed an agreement with Synoptics Communications, a Xerox PARC spin-off, to
create such an option. Shortly thereafter, 3Com announced that it was working on a similar specification (Keefe, 1987). While many engineers frowned on the initiative, as it did not create a faster or more efficient version of the original standard, its proponents asserted that the extension would allow customers to exploit their existing telephone wiring installations as well as greatly simplify the setting up and maintenance of their LANs. Creating such an extension of Ethernet involved making substantial changes to the original specification. In addition to modifying the wiring, the developers of this extension intended to change the topology of the network from a bus-based to a star-shaped system. This would involve introducing a new component -- the hub concentrator – that would carry out network management functions. In proposing such an overhaul of the institutional rule, the developers were not being constrained by the original specification. Rather, they viewed certain key components of the original standard -- in this instance, the transmission medium, topology and the distance between two nodes – as being mutable.

However, there is also a negative side to the generation of numerous extensions to a standard. To the extent that they suggest diverse directions for future evolution, generating multiple extensions is antithetical to the purpose of a having a standard in the first place. Given this scenario, how can members of a field ensure that the extension generation does not lead to fragmentation of the market based on the standard?

**Extension ratification**

In order for an extension to gain legitimacy within the field, it needs to be ratified within the standards development organization. These forums typically have clearly specified procedures for standards creation that specify how proposals are put forth,
debated and resolved. In order to develop a specific extension, the standards organization formally authorizes the formation of a “working group” in which representatives from different firms participate and develop the actual interface (Lehr, 1992). The specification does not become final until all comments and objections are answered fairly and objectively. This method of consensus building can (potentially) serve a strong filter to the number of extensions developed by a committee. Given its design, this process is inherently contentious in nature with complaints often being voiced that standards development through committees is too slow and/or too political. Given this scenario, actors within these forums must perform a delicate balancing act. They need to abide by rules of due diligence and openness in order to ensure that the standardization process is perceived as impartial while simultaneously making sure that specifications are set in a timely fashion so as to maximize their market impact.

On this front, the working group associated with the Ethernet standard performed admirably, rapidly ratifying a number of significant extensions to the original specification through the 1980’s that continues to this day. This was largely due to the ability of the actors within the group to forge consensus and prevent the standardization process from becoming bogged down by the self-interests of individual actors. The development of the telephone-wire extension of the Ethernet standard provides a good illustration of these dynamics. Soon after the formation of a group in July 1987 to investigate ratification of this extension, two main camps involving DEC/3Com and HP/Synoptics respectively, began lobbying for their versions to be developed as the official specification. For a while, it appeared as if the proposals were evenly matched, and the stage was set for a heated showdown within the standards committee. However,
the struggle between these two loosely aligned groups of vendors was resolved at the March 1988 meeting when DEC/3Com withdrew their proposal and cleared the way for unanimous approval of the HP/Synoptics approach. Even though the committee did not adopt its proposal, neither DEC nor 3Com viewed the unfolding scenario as a defeat. According to DEC officials, the differences between the two approaches were less important than the larger concern of promoting Ethernet against other LAN schemes. As Robert Becker, manager of DEC's Ethernet LAN Marketing Group, put it, "It's in everyone's best interest to promote a unified front through [Ethernet]" (Maglitta, 1988). This ability to establish consensus among competing interests within the group has been key to the timely development of extensions to the Ethernet standard.

An interesting outcome of this elaborate process of extension ratification was that there was no clear technical logic underlying the sequence of extensions developed. Rather, they more reflected the individual ability of actors and the collective will of the working group to engage in standardization activity. As an illustration, ratification of the Broadband Ethernet (10Broad36) extension was viewed primarily as a means to placate proponents of an alternate technology that had been rejected while developing the original Ethernet specification. This suggests that the specific procedural features followed as well as the strategic dynamics that unfold within an institutional forum wield a strong influence on the number and types of extensions developed.

Moreover, it is important to note that ratified extensions can vary significantly in the extent to which they modify the original standard. Some extensions are more incremental in nature – for example, Thin Ethernet (10Base2) employed thinner coaxial cable but otherwise was the same as the original standard. At the other end of the
spectrum, extensions can be path creating (Garud and Karnoe, 2001) in nature in that they not only significantly address limitations associated with the extant specification but also have the effect of enabling the standard to evolve along trajectories not originally envisioned. Such extensions fundamental reconceptualize the existing standard and advance a new set of design principles that become the basis for future evolution of the specification. Telephone wire Ethernet (10BaseT) represented such an extension in that the key ideas proposed in it – telephone wiring, active hubs and short distances between nodes in the network – were far removed from those incorporated in the original Ethernet specification. However, these ideas were to become a central aspect of the extensions that were developed subsequently (Seifert, 1998).

Overall, the ability of actors to collectively ratify extensions to a standard can radically transform the ongoing dynamics within a field. These extensions have the additive effect of dramatically increasing functionality associated with the standard. In certain cases, they represent conceptual breakthroughs that remove constraints identified with the original standard and open up a range of opportunities for future evolution of the specification that were not apparent earlier. Such path-creating extensions can significantly extend the longevity of a standard. As Bob Metcalfe, the inventor of Ethernet commented about the specification’s endurance:

“I predicted that 2003 would be the last year in which a new Ethernet product would be announced. But I made that prediction based on the 10Mb/s limit. That was before I saw, as others saw, that you could speed it up. That’s been going on steadily. And then when you go switched and eliminate collisions entirely, the sky’s the limit” (Desmond, 1998).

Extension incorporation
The preceding discussion indicated that actors often make substantial changes to the technical standards on which a field is based. One consequence of these changes is that over time, the specification bears little resemblance to the original standard. As part of shaping the migratory costs perceived by consumers that subscribe to earlier versions of the standard, actors often engage in strategies that involve changing the identity of the specification over time. Specifically, extensions are often symbolically incorporated into the original standard even as the number of common technical features across these versions reduces significantly.

Along these lines, members within the field referred to the extension on thinner coaxial cable as Thin Ethernet, the version on twisted-pair wiring as Telephone-wire Ethernet and the 100 Mbps variant as Fast Ethernet. This norm for naming extensions with the suffix Ethernet has remained even though these additions, from a technical viewpoint, bear virtually no resemblance to the original standard. At this stage the identity of Ethernet is solely linked to the frame format – a far cry from its early days when it represented an integrated and specific method for enabling data communication.

As Bernard Daines, founder of Packet Engines, an Ethernet-based start-up, observed,

“What is Ethernet today? It’s not a black cable looping around computers. It’s not even a hub anymore. Ethernet is a well-understood, well-known arrangement of data and some rules that go along with it that is carried using a dozen different media and signaling types at four or five different speeds. The common element is the frame format, and to some extent, the packet format. No matter how I transmit my signal from one station to another, when it gets back into the frame, you can pass it to another station and (the data) is still there” (Network World, 1998).

The quotation above suggests that incorporating a broad range of extensions into a standard often require changing the identity of the specification over time. The term
“Ethernet” now more accurately represents a family of standards that are linked to one another minimally through a common frame format. The process of extension incorporation then is one in which technical differences between the extensions and the original specification are deemphasized and symbolic similarities across variants is played up. As more extensions are developed over time, it is conceivable that the links across these becomes even more abstract. However, maintaining this link is crucial as by invoking the common symbolic identity across extensions, actors provide an image of continuity and persistence to the specification. In other words, actors embed the multiple extensions that they develop within the existing institutional mosaic in order to leverage the legitimacy benefits associated with the original standard. This, in turn, impacts the level of end user comprehension and acceptance of these extensions (Hargadon and Douglas, 2001). Put differently, such a symbolic strategy enables actors to symbolically “lock-in” a specification in the minds of consumers even as they substantially overhaul the specification technically. These dynamics are best captured by a statement made by Vinod Bhardwaj, founder of Kalpana Systems, a manufacturer of Ethernet switches,

“So Ethernet will keep on evolving, but it is quite possible that it is called Ethernet after 50 years even though it will have, in effect, changed from an ape to a human being” (Network World, 1998).

Effects of extension development

Since the formalization of the first Ethernet specification in 1983, over 10 proposals have been ratified as official extensions to the institutional rule (see Table 3 for a partial list of Ethernet extensions developed). What began as a 3Mbps standard implemented on coaxial cable in 1973 has grown to a 1Gbps specification functioning on telephone wire in 2000. The initial standard was defined in terms of the following key
dimensions: speed, wiring, mode of transmission, topology, maximum distance between nodes and frame-format (see Table 4). Over time, the extensions developed have involved changing every one of these dimensions except the frame-format. These extensions have prolonged the viability of a specification significantly beyond its original expectations. Moreover, the standard has shown no signs of relinquishing its dominance in terms of market share, which was estimated at about 70 percent in 1998. This is particularly remarkable given the fierce competition that Ethernet has faced over the years from competing LAN standards such as Token Ring, Arcnet and FDDI. These dynamics within the LAN marketplace are testimony to the significant role that extensions can play in increasing the long-term viability of a technology standard. Overall, this points to the need for adopting a more dynamic conceptualization of the relationship between actors and the technology standards that they create. Rather than view actors as being significantly constrained by the rules they create, we need to examine the mechanisms they employ to leverage standards even as they change them.

DISCUSSION

In this paper, we employed a detailed historical analysis of the Ethernet LAN standard to elaborate on three sub-processes associated with technology standards evolution, which we termed generation, ratification and incorporation, respectively. The ability to generate extensions was partly a function of the anticipatory nature of the specification, which implied that that were developed in advance of the formation of a product market and only partially structured the interactions among members within the
field. This implied that an initial standard set at a point in time was unlikely to address the needs of all members of the field over a period of time. More intriguingly, this suggested that incompleteness in the original standard might in fact be a virtue as this would enable actors to build relevant extensions to the standard as the field evolved.

Extension generation, at an underlying cognitive level, is a function of the degree to which members within the field interpreted the existing specification as being mutable. On this front, the collective-level imagination displayed by members of the field played a significant role in extension generation. A multitude of reasons – limitations in the extant specification, competitive pressures (both from within and outside the field) and ongoing improvements in constituent as well as complementary technologies – underpinned proposals for extension development. However, many of these would have fallen through if the collective took a rigid approach and defined many of the components of the extant specification as being immutable. To the extent that members of the field took a more inclusive and flexible approach to interpreting the existing rules, they opened up avenues for extension generation. On this front, it is important to note the role that start-ups can play in the generation of key extensions (see also Leblebici et al, 1991). Note, also, that there is a negative side to taking too flexible an approach to extension generation.

In terms of extension ratification, the ability of actors within the committee to forge consensus and prevent the process from becoming bogged down by the self-interests of individual actors is a key differentiator across different standardization initiatives. Given the collective and intensely negotiated nature of the ratification process, however, there is no clear technical logic underlying the sequence of extensions developed. This finding stands in contrast with cyclical models of technological change.
which suggest that there is an inherent techno-economic logic to the development of extensions to a standard (Hughes, 1983; Khanna & Iansiti, 1995; Tushman & Murmann, 1998). Moreover, our analysis suggests that it is important to distinguish between extensions that are merely incremental variations on the original specification and those that are “path creating” in nature. The latter represent conceptual breakthroughs that remove constraints identified with the original standard and often open up a range of opportunities for future evolution of the specification that were not apparent earlier.

And finally, extension incorporation relates to the need to maintain compatibility and coherence across different extensions even as these might diverge significantly at a technical level. In order to do this, extensions are often symbolically linked to the original standard in terms of it branding. Doing so ensures that the extension is incorporated within the existing institutional mosaic which enables it to leverage the legitimacy benefits associated with the standard. A key implication of engaging in such symbolic strategies is that the identity of a standard may change significantly over a period of time. However, such a strategy of extension incorporation enables the standard to be completely rehauled (from a technical viewpoint) over a period of time while retaining a common identity among members of the field. Put differently this strategy has the effect of creating a sense of continuity, or symbolic lock-in, of the standard.

By employing a common symbolic identity and minimizing differences across extensions, actors can create an impression of persistence of the existing technology standard. However, it is important to distinguish such institutional persistence from the notion of “lock-in” developed in the economics literature (David and Greenstein, 1990). As the narrative demonstrates, standards persistence is mainly due to active institutional
agency by members of the field in terms of engaging in processes of extension generation, ratification and incorporation rather than a result of the constraining effects and inertial pressures of an institutional rule on the installed base of members vested in it. This suggests the need for a more active and dynamic notion of “lock-in” than previously conceptualized – one that factors in the use of symbolic strategies in creating a semblance of standards persistence.

The model of technology standards evolution elucidated in this paper provides a way of understanding the nature of interaction taking place between actors and the rules they create within highly dynamic contexts (Brown and Eisenhardt, 1997). In such settings, the high levels of uncertainty combined with the rapid rate of underlying technological change make it imperative for actors to continually modify the technology standards associated with the field or risk becoming irrelevant. And yet, in engaging in such change, these actors aspire to leverage the benefits they gain from conforming to the existing standard. Actors address these two objectives simultaneously by generating extensions to the rules, ratifying these extensions through a process of collective consensus and incorporating them within the institutional mosaic associated with the original standard. By engaging in these three processes, actors simultaneously build upon the enabling properties of the extant standard as well as address its perceived constraints (see Table 5 for an elaboration of the model of technology standards evolution that we have developed in this paper). This suggests that much of the activity associated with standards development takes place after, rather than prior to, the emergence of the original anticipatory standard.
In all of this, it is also important to note that institutional change via extension development is fraught with fragility in that it consists of a number of aspects that can unravel quite easily. These include the inability to create relevant extensions, ineffective resolution of disputes among members and failure to convince end-users of the value provided by an extension. Overall, this study provides theoretical insights for understanding technology standards evolution as a process of extension development and advocates a closer examination of these extensions in terms of understanding their origins, level of change invoked, ratification process and impact.

This study also indicates the need to more closely observe the role played by incumbents as institutional entrepreneurs (Selznick, 1957; Dimaggio, 1988; Fligstein, 1997; Greenwood & Suddaby, 2006) who shape rules and logics. The historical narrative indicates that such agency can be quite nuanced. Incumbent actors are not necessarily constrained by extant institutional rules and do expend effort to make changes to them. The administration of such changes often takes place within institutional forums that serve as coordination and dispute resolution mechanisms. Even as such changes are made, actors often couch them in terms of the existing institutional mosaic in order to leverage legitimacy benefits (Hargadon and Douglas, 2001). These different facets of agency point to the social and political skills that actors demonstrate when involved in constructing and navigating institutional landscapes (Fligstein, 1997; Garud, Jain and Kumaraswamy, 2002). On this front, thick descriptions of the actors and the institutional
forums involved in the microdynamics of institutional change can contribute to a richer understanding of the myriad strategies deployed in institutionalization projects.

CONCLUSION

In highlighting the extensibility of technology standards and the active role of agency in fostering technology standards evolution, we provide a pathway for understanding how an important debate within the literature on institutions can be resolved. This relates to managing the dynamic tension between institutional integrity and responsiveness. Selznick (1992:326) posed the problem as follows -- “the challenge is to maintain institutional integrity while taking into account new problems, new forces in the environment, new demands and expectations”. In the terminology employed in this paper, this challenge translates into harnessing the enabling aspects of a standard while not being constrained by it in the future. By establishing a provisional or anticipatory standard, developing extensions over time and incorporating these as part of the original rule, actors can create technology standards that “avoid insularity without embracing opportunism” (Selznick, 1992: 326). Such specifications are more likely to persist over time (and sometimes enjoy unexpected longevity) as a consequence of their adaptability. Rather than view these arrangements as “locked-in” or “taken for granted”, this research advocates the need for a deeper understanding of the mechanism underlying the creation of standards that are extensible in nature.

While we have developed my insights on the basis of a single narrative, there is evidence to suggest that this model of technology standards evolution is useful in explaining the evolution of a number of other IT-based specifications. The persistence of TCP/IP, a key computer networking protocol, over more vaunted alternatives, has been
attributed to the continual development of extensions on the original specification (Computerworld, 1986). The increasing prominence of Linux as an operating system in corporate environments can be traced to an ongoing process of specification development involving multiple actors across the globe (Raymond, 2000). In addition, there are scenarios in which the lack of (or delay in) development of an extension to a standard has contributed to a logjam in activities taking place within the extant field. The protracted development of IPv6 (the next generation of the IP protocol) and the recent travails of Microsoft (in the development of the next generation of Windows) are cases in point. These scenarios point to the need for more studies that examine extension development on a technology standard as a means of further advancing the theoretical frame proposed in this paper. In addition, it would be useful to examine the applicability of this model to non-IT contexts in which standards need to display a high degree of responsiveness.

This study also vividly demonstrates the underlying social and political dynamics that unfold during the evolution of a technology standard. In particular, the narrative indicates that the extensions developed were not simple responses to technical and economic exigencies, but rather reflected a complex resolution of the interests of the individual actors and the institutional forum involved. This suggests that an understanding of the content of these standards requires an examination of the intentional, directive and conflict-laden processes involved in their constitution (Dimaggio, 1991). As we have seen, institutional agency in such scenarios can be quite sophisticated, with actors and institutional forums working in conjunction with one another to both depart from and conform to the existing institutional rule. Overall, this paper contributes to developing a more sociologically informed theory of technology
standards evolution.

In doing so, it also opens up a number of avenues for future research. One direction would be to examine how the extent to which actors design an anticipatory standard impacts the structuring of activities and subsequent development of an emerging field. In conditions of high uncertainty, it may be more prudent to follow the policy of “standardize a little, implement a little, then standardize a little more” as a way of resolving such uncertainty, rather than freeze the specification up front and leave little room for the development of extensions in the future. Related to this, studies can also examine the conditions under which fields become completely institutionalized and changes in technology standards take place through a process of substitution rather than extension development.

A second line of research could look at which actors (newcomers or incumbents) introduce extensions and more generally, how the membership as well as norms governing a collective impacts the creation of extensions to a specification. Related to this, research could examine the different kinds of governance mechanisms that collectives employ in order to coordinate and regulate the development of extensions. Given that this study has focused on the scenario in which a collective of firms is involved in extension development, another line of inquiry would be to examine the incentives that individual firms create to foster the development of extensions on technology standards over which they have proprietary control.

A third direction for research involves examining the decisions that actors make in terms of incorporating extensions. To what degree do they emphasize connections to the original institutional mosaic (and what mechanisms do they use to do this), and are
there cases where they deemphasize these linkages? While there are legitimacy benefits
to be gained by emphasizing the similarity across extensions, these should be factored
against the costs incurred (in terms of lack of adoption) if there is a perceived lack of
novelty in the extensions. Overall, there is a need for a better appreciation of the role of
institutional agency in the structuring of emerging fields. Research in this domain can
provide us with deeper insights as to why certain technology standards fail to register a
long-term impact while others enjoy unexpected longevity – evolving from ape to human,
in the process.
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<table>
<thead>
<tr>
<th>Research Procedures</th>
<th>Research Principles</th>
<th>Application to this research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop a research question</td>
<td>Identify phenomenon of interest</td>
<td>Substantive Issue: How do compatibility standards evolve?</td>
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<td></td>
<td></td>
<td>Theoretical Interest: Specify processes underlying compatibility standards evolution</td>
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<tr>
<td>Conceptual background</td>
<td>Build theoretical sensitivity</td>
<td>Reviewed extant research on compatibility standards from economics, sociology of technology</td>
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<tr>
<td></td>
<td></td>
<td>and institutional theory</td>
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<tr>
<td>Data site selection</td>
<td>Theoretical Sampling</td>
<td>Chose the Ethernet standard within the LAN industry – a strategic research site where the</td>
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<tr>
<td></td>
<td></td>
<td>phenomenon of interest could be observed/studied</td>
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<tr>
<td>Data collection</td>
<td>Multi-source, multi-method approach</td>
<td>- Comprehensive review of business/trade journals available online</td>
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<tr>
<td></td>
<td></td>
<td>- Interviews with industry participants (members of standards committee)</td>
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<tr>
<td></td>
<td></td>
<td>- Referred to books/articles/websites covering the LAN industry, the standardization</td>
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<tr>
<td></td>
<td></td>
<td>process and technical details; accessed consultant reports</td>
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<tr>
<td></td>
<td></td>
<td>- Created timeline of events from these sources</td>
</tr>
<tr>
<td>Data analysis</td>
<td>• Initial qualitative accounts</td>
<td>- Created initial narrative from timeline of events; identified emerging themes</td>
</tr>
<tr>
<td></td>
<td>• Raise level of theoretical abstraction</td>
<td>- Collected additional data on case; iterated between theory and data until “theoretical</td>
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<tr>
<td></td>
<td>• Refine theoretical frame</td>
<td>saturation” occurs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Compared and contrasted analytic narratives with existing theory; identified emerging</td>
</tr>
<tr>
<td></td>
<td></td>
<td>insights</td>
</tr>
<tr>
<td>Year</td>
<td>Event Description</td>
<td></td>
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<tr>
<td>------</td>
<td>-------------------</td>
<td></td>
</tr>
<tr>
<td>1973</td>
<td>Ethernet invented at Xerox PARC by Robert Metcalfe and David Boggs</td>
<td></td>
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<tr>
<td>1978</td>
<td>Principal Ethernet patents issued to Xerox</td>
<td></td>
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<tr>
<td>1980</td>
<td>DIX (Digital-Intel-Xerox) alliance formally announced in May – publishes Ethernet specification (for licensing) in September; IEEE forms 802 committee to set LAN specifications in February; first meeting held in May</td>
<td></td>
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<tr>
<td>1981</td>
<td>Ethernet-based products available commercially; cost of Ethernet card + cable ~ $5000</td>
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<tr>
<td>1983</td>
<td>IEEE formally approves Ethernet specification; formally referred to as 10Base5</td>
<td></td>
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<tr>
<td>1984</td>
<td>Multiple proposals for extending the original Ethernet specification under consideration within the IEEE; price of Ethernet card + cable drops to ~$500</td>
<td></td>
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<tr>
<td>1985</td>
<td>IBM debuts its Token Ring specification in October - works on high-grade telephone wire</td>
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<tr>
<td>1986</td>
<td>AT&amp;T and Synoptics jointly announce development of Ethernet-over-telephone-wire extension</td>
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<tr>
<td>1987</td>
<td>3Com announces development of Ethernet-over-telephone-wire extension; Starlan (1Base5) extension formally approved by IEEE; HP initiates study group within IEEE to investigate feasibility of developing an Ethernet-over-telephone-wire option; 5 proposals for specification under investigation by the IEEE in October</td>
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<tr>
<td>1988</td>
<td>DEC/3Com withdraw their proposal to allow unanimous approval of HP/Synoptics proposal – actual specification work on extension begins</td>
<td></td>
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<tr>
<td>1990</td>
<td>IEEE formally approves Ethernet-over-telephone-wire extension; formally referred to as 10BaseT; products based on the extension flood market; Ethernet board prices reach ~ $200</td>
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<tr>
<td>1992</td>
<td>Grand Junction announces development of 100Mbps Ethernet extension; HP &amp; AT&amp;T announce development of a rival 100Mbps option; IEEE forms the High Speed Ethernet study group to evaluate these proposals</td>
<td></td>
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<tr>
<td>1993</td>
<td>17 vendors form Fast Ethernet Alliance; IBM joins HP and AT&amp;T to form 100-VG AnyLAN forum; IEEE recommends development of two specifications for high speed Ethernet</td>
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<tr>
<td>1995</td>
<td>Fast Ethernet and 100-VG Anylan extensions formally approved by IEEE; formally referred to as 100BaseT and 100VG-AnyLAN respectively</td>
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### TABLE 3
Key extensions developed on original Ethernet specification, 1985-1995

<table>
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<tr>
<th>IEEE Std 802.3 document</th>
<th>Industry Name</th>
<th>Additional Functionality</th>
<th>Principal Sponsors</th>
<th>Clauses added</th>
<th>Size of WG*</th>
<th>Size of BG**</th>
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<tbody>
<tr>
<td>802.3-1985, Original 10Mbps standard, MAC, PLS, AUI</td>
<td>Thick Ethernet 10BASE5</td>
<td>Original Ethernet</td>
<td>DIX coalition</td>
<td></td>
<td>43</td>
<td>112</td>
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<td>802.3a-1988 10Mbps MAU</td>
<td>Thin Ethernet 10BASE2</td>
<td>Ethernet over thinner coaxial cable</td>
<td>Clause 10</td>
<td>50</td>
<td>126</td>
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<td>802.3b-1985 10Mbps Broadband MAU</td>
<td>Broadband Ethernet 10BROAD36</td>
<td>Ethernet over broadband cable</td>
<td>Clause 11</td>
<td>69</td>
<td>104</td>
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<tr>
<td>802.3e-1987 1Mbps MAU and Hub</td>
<td>Starlan 1BASE5</td>
<td>Ethernet over twisted pair (lower speed)</td>
<td>AT&amp;T</td>
<td>Clause 12</td>
<td>68</td>
<td>106</td>
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<tr>
<td>802.3i-1990 10Mbps UTP MAU</td>
<td>Twisted-Pair Ethernet 10BASE-T</td>
<td>Ethernet over telephone wire</td>
<td>Synoptics/HP</td>
<td>Clauses 13-14</td>
<td>123</td>
<td>184</td>
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<td>802.3j-1993 10Mbps Fiber MAU’s</td>
<td>Fiber Ethernet 10BASE-FP, FB and FL</td>
<td>Ethernet over fiber cabling</td>
<td>Clauses 15-18</td>
<td>80</td>
<td>154</td>
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<td>802.3u-1995 MAC, PL, MAU, Repeater for 100Mbps operation</td>
<td>Fast Ethernet 100BASE-T</td>
<td>Faster version of Ethernet</td>
<td>Grand Junction/3Com</td>
<td>Clauses 21-30</td>
<td>134</td>
<td>117</td>
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* WG: Working Group  
** BG: Balloting Group
<table>
<thead>
<tr>
<th></th>
<th>Original Ethernet (10Base5)</th>
<th>Fast Ethernet (100BaseT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>10 Mb/s</td>
<td>100 Mb/s</td>
</tr>
<tr>
<td>Wiring</td>
<td>Coaxial cable</td>
<td>Telephone</td>
</tr>
<tr>
<td>Mode of transmission</td>
<td>CSMA/CD (Shared)</td>
<td>Dedicated (Switched)</td>
</tr>
<tr>
<td>Topology</td>
<td>Bus</td>
<td>Star</td>
</tr>
<tr>
<td>Maximum segment distance between nodes</td>
<td>500 m</td>
<td>100 m</td>
</tr>
<tr>
<td>Frame format (max size)</td>
<td>1518 bits</td>
<td>1518 bits</td>
</tr>
<tr>
<td></td>
<td>(same as original)</td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 5
A process model of technology standards evolution

<table>
<thead>
<tr>
<th>Stage of process</th>
<th>Empirical evidence from narrative</th>
<th>Key theoretical facets related to process</th>
</tr>
</thead>
</table>
| **Extension Generation**  | * Limitations in initial technology standard identified  
                             * Competitive pressures on field  
                             * Numerous extensions proposed  
                             * Number of extensions proposed by start-ups  
                             * Some extensions propose extensive rehaul                                                      | * Level of specificity of anticipatory standard  
                                                                                                   | * Fit of anticipatory standard with evolving user needs/changes in underlying technologies  
                                                                                                   | * Degree of openness associated with anticipatory standard  
                                                                                                   | * Level of mutability associated with standard                                                      |
| **Extension Ratification**| * 5 proposals ratified by working group as extensions to the original Ethernet specification during 1984-1990  
                             * Ethernet-on-telephone-wire extension proposed in 1987 and ratified in 1990                    | * Governance mechanisms that enable development of extensions  
                                                                                                   | * Number/Types of extensions on a specification that are formally ratified  
                                                                                                   | * Level of change proposed in extension/ path creating nature of extensions                         |
| **Extension incorporation** | * Most extensions symbolically referred to as part of Ethernet family – Thin Ethernet, Telephone wire Ethernet, Fast Ethernet, etc  
                                  * Common technical aspects across Ethernet extensions now reduced to frame format                 | * Symbolic “lock-in” with original standard  
                                                                                                   | * Technical linkages minimized between extensions and original specification                         |