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THE DEVELOPMENT OF THE LOCAL AREA NETWORK MARKET AS DETERMINED BY USER NEEDS

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Events in the Local Area Network (LAN) market are used to illuminate recent developments in the economics of technical standards. Several analytical themes emerge: the role of complementarities in social increasing returns, the strategic importance of standardization in determining industry structure, and the coordination problems facing the sponsor(s) of a new technology. The contrast between office LANs, with a traditional industrial organization, and factory LANs, where large users attempted to set a standard, is central.

KEY WORDS: Technology, Standards, Market Structure, Computer, LAN

1. INTRODUCTION

The recent analytical literature on interface standards has delivered a great many fascinating insights into the interaction between business strategy, industry competition, and the rate and direction of technical progress.[1] The focus on interface standards as a phenomenon seems warranted in the present era, since problems of compatibility appear to characterize information technologies.[2] Further, the literature has been quite rich analytically; the strategic decisions of particular firms, industry structure, and expectations about the future path of technology have been treated as endogenous. Yet, as is so often the case, the supply of analytical insights has outstripped empirical analysis. Despite a few recent breakthroughs, little is known about the implications of the standard setting process in real information product industries.[3]

This paper will attempt to make practical use of the insights of the analytical literature to understand technical advance and industry structure in a specific information technology: local area networks (LANs). In particular, we will concentrate on two important markets served by LAN technology, the office and the factory.

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[1]See Arthur (1983), Cabral (1988), David (1985, 1987), Farrell and Saloner (1985, 1986, 1987, 1988), Farrell and Shapiro (1988), Farrell and Gallini (1986), Katz and Shapiro (1985, 1986).

[2]See David (1987) for a discussion of this point and for a comparison to standard-setting issues in earlier technologies.

[3]But see Besen and Saloner (1988), David and Bunn (1988), Sirbu and Zwimpfer (1986) Sirbu and Hughes (1986), Sirbu and Stewart (1986).

LANs link computers and computer-controlled devices together.[4] Levy (1985) defines a LAN as "a data communications facility, usually owned by one organization, providing a common transmission facility for dissimilar devices, with control and protocols to permit information and resource sharing within a building." For example, in an office environment a group of workers might share common programs and data files. These files could be stored on a large hard disk connected to a "file server" computer on the LAN. The LAN would offer each of the workers access to the files and programs nearly as quickly as if they were stored on a hard disk in the worker's own computer. LAN performance characteristics are very different from those of the telephone network, which provides slow access to a great many different places. A LAN links a relatively small number of devices together in a high-performance way. In the office environment, this permits the sharing of resources across a number of workers, as the hard-disk example suggests.

In addition to sharing resources, LANs offer the possibility of effective communication. A factory might use numerically controlled (NC) machine tools and automatic materials handling. In that environment, a LAN can help communication from the plant's managers to the machines, as when there is a changeover to a somewhat different product. It can also serve as a conduit for information about the state of the factory as a system, as the assorted "smart" machines can report problems to the controlling entity. Some of these communications can require the rapid transmission of large messages; to understand how and why the factory has gotten into a bad state, for example, the managers may wish to have "captured" the entire recent history of many machines' actions. This will involve substantial communication and recording. Not surprisingly, LANs first entered the control of physical systems where very rapid response is extremely valuable, such as the Navy's AEGIS ship-control system. The installation of a LAN will be economically viable when there are a great many intelligent devices – computers or their peripherals, NC machine tools, etc. – in a small area, and when there is a return to having the devices communicate data rapidly and easily. Thus LANs have two fundamental complements in demand: intelligent devices, and organizational or other reasons for rapid communication. Substitutes for LANs include other mechanisms for communication, such as direct point-to-point wiring, the linking of end-users to a central mainframe computer, or the use of a broader network like the phone system. We will argue that, as the theory suggests, events in the LAN market are strongly influenced by the structure of and conduct in markets for complements to LANs.

Since LANs are complex data communications networks serving complex data processing equipment, the standard-setting process in LANs themselves is very complex. Indeed, there have been a series of disputes about LAN standardization at nearly every level; physical connection[5], protocols for the content of messages, and equipment-to-LAN and equipment-to-equipment information exchange interfaces. We will confine our attention to the "software" protocol and exchange interface issues.

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[4]See AICPA (1985) for an introduction to LANs from the point of view of the user.

[5]Physically, LANs are differentiated by three basic features. First, they consist of transmission cables: coaxial cable, fiber optic cable, or "twisted pair" copper wire. Cabling plans are designed to be optimized with the vendors' equipment. Secondly, LANs are differentiated by the method of access, which may be random or deterministic. If it is random, then the Carrier Sense Multiple Access (CSMA) technique is used. Collisions of transmitted data are monitored by collision detection or avoidance protocols. If access is deterministic, then a "token" with information about which station is transmitting is passed along the network. Thirdly, LANs can be distinguished by their topology star, ring or bus. Several competing standards exist for the physical part of LANs.

2. ON APPLYING THE ECONOMIC THEORY OF STANDARDS

The economic theory of standards, as practiced in the papers cited in footnote 1, has produced a series of insights and results. This section attempts to reiterate the main points in a way which helps bridge to their application in practice.

- Network industries are characterized by social increasing returns to scale and the need for broad coordination to achieve those returns. These arise for at least two reasons. The first is the need for compatibility between different complementary inputs. For example, computers and software must interact. "Fragmentation" in the computer industry, i.e., a situation in which not all computers can run the same software, raises the number of times the substantial "first copy costs" of writing software must be borne. The second reason arises with particular force in communications networks, like the ones under study. Intelligent communicating entities must agree on how they are to be connected, the language that they are going to use to communicate, and the subjects they are going to talk about. The more dissimilar the communicating entities, the more difficult this process will be.
- Thus there will be economic forces for coordination in a network industry. These forces can take the industry toward or away from the social optimum. They can underscore or overwhelm the strategic decisions of any particular firm or firms. They can be played out by the explicit cooperation of firms or through decentralized processes.
- What is the meaning of these analytical points for studies of information technologies and their standard setting processes? At least two points seem clear. First, and most obvious, is the emphasis on the study of coordination *per se*. We should expect industry structure, in particular, to be heavily influenced by the need for coordination. Second, and perhaps less obvious, is an implication about the appropriate framework of analysis for any particular information technology. Not only the coordination forces in the technology at hand, but also forces in *complementary technologies* can exert powerful influences.
- Once an industry has begun to exploit coordination economies, there is a tendency to "lock in" to a particular method. Particularly when some of the decisions about complementary inputs are long-lasting, industry participants will not lightly leave an established method. In information technology, many of the complementary inputs are computer hardware and software, whose costs are largely sunk. Thus one should expect some permanence to *de facto* standards, even in the face of later superior technologies.
- Interested parties will recognize this tendency to lock in to particular standards. This has two implications. First, there is a strategic motive to influence standard-setting. Firms would like to see their product established as a proprietary standard, or at the least to ensure that the standard that obtains is compatible with their product. On the other hand, firms will not lightly commit resources to a particular standard before it is clearly established. Thus we should expect rent-seeking in the establishment of standards in some circumstances, and reluctance to participate in a nascent standard in others.
- What is the implication of these dynamic points for the analysis of industries? We expect to see attempts to influence the conditions of competition through the standard setting process. Sellers will try to encourage proprietary standards for the market power they provide. Buyers will seek to increase the extent of competition by the breadth of standardization. If all sellers must produce to the same very narrow

technical specifications, then product differentiation advantages will be hard to establish. Much the same point holds dynamically; if individual buyers are locked in to the products of individual sellers, we can expect much less competition than if buyers can switch without loss of sunk costs. This point can be seen from the other side as well, to clarify that its welfare economics are ambiguous; the appropriability regime of the industry will be partially determined by the extent of standardization.

- Since the establishment of a standard is fundamentally a coordination activity, we should expect to see explicit attempts at coordination. Firms will attempt to influence other firms' technological expectations; for example, to overcome reluctance to commit to a particular coordinated outcome. Thus the interplay of reputations, credibility, and related matters will be an important determinant of standard-setting process outcomes. In thinking about this, it is reasonable to anticipate that the issues that arise in bargaining theory will be relevant. Those attempting to coordinate across different firms or different sectors of the economy will need to find a way to make coordination in the perceived interest of all the parties. To overcome technological reluctance, the holder of a potential proprietary standard might well attempt to decrease its own market power by encouraging competition.
- There will be substantial uncertainty about the standard setting process at crucial junctures. Firms will have different and incomplete knowledge about the future direction of technical change, and this will lead them to differ on the optimal direction of their own activities. Thus we can expect to sometimes see fragmentation even in those industries which will eventually be a single standard. Similarly, we can expect differences of opinion about the degree to which technology should advance before it is "frozen" into a standard.

These points lead to an analysis of the standard-setting process as an applied exercise in the study of industry structure. The establishment of a standard or standards, whether recognized by a standard-setting body or simply *de facto*, sets the conditions of competition.

3. "OFFICE" LANS

LANs in offices connect microcomputers, minicomputers, mainframes, and peripherals in support of white-collar functions. Connections are local, often to the same building or floor, or to a few nearby buildings.

Office-oriented LANs became technically and economically viable in the early 1980's, when it was possible to consider installing a LAN with costs per connected device in the hundreds rather than thousands of dollars.[6] Since LANs gain their utility from linking together separate intelligent devices, the rapid growth in the installed base of personal computers in the early 1980's provided an opportunity for them. The market for this service was, after only a few years, quite large. The International Data Corporation (IDC), reports that in 1985, 60,000 microcomputer LANs were already installed in the work environment, and the rate of installation was about 30,000 systems a year (Finlay, 1986). According to a Goldman Sachs estimate, 1987 LAN revenues were approximately $1 thousand million, and the market is expect to grow

[6]See the quote from John F. Shoch, president of Xerox Office Systems Division, in "Linking Office Computers: The Market Comes of Age," *Business Week*, May 04, 1984. Mr. Shoch put 1980 costs of connecting at $4,000/terminal: 1984, $750.

at 30–35% per year. (See the January 6, 1987, *Investment Research Report*.) To understand the evolution of the "office" LAN market, we will attempt to put it in the context of broader events in the computer field at that time, especially in the microcomputer "revolution".

IBM in the PC Marketplace: the PC/XT/AT Standard

The computerization of white collar work was familiar by the early 1980s. For three decades, mainframe and minicomputer-based business data processing had steadily advanced. (See Phister (1979).) For half a decade, microcomputers had been used as single-person systems in the office environment. A change in kind as well as in degree occurred, however, with the entry of IBM into the microcomputer market. The change in degree was the ongoing technical progress in microcomputers. The advance from microcomputers based on 8-bit microprocessors to those, like the IBM PC family, with 16-bit capability, permitted a substantial increase in office applications power.

The change in kind had implications for the development of the office LAN market. IBM's reputation, marketing ability, and other assets helped establish the PC-XT-AT *de facto* standard for office microcomputers. (We will discuss competing personal computer standards below). One particular IBM strategic decision, to have an "open architecture" was particularly influential on the development of office microcomputing. The existence of add-on hardware "slots" in IBM PCs permitted third party hardware vendors to provide innovative products, and the proliferation of IBM workalike "clones" led to a remarkable era of coordination and compatibility in office computing. The establishment of the *de facto* PC-XT-AT standard shifted the supply of complements to microcomputers. With a standard hardware "platform" and operating system, barriers to entry into complements were low. In particular, spreadsheet (Lotus 1-2-3) and word processing (Wordstar, Microsoft Word, WordPerfect) software quickly became very broadly-used, general purpose tools, facilitating the broad diffusion of microcomputers. Hardware complements grew in importance as well: special purpose add-in cards established niche markets, and broadly-used peripherals, such as monitors, printers, and disk drives, entered a period of rapid technical progress. (See Cole (1985) for measures of the price-performance ratio of disk drives; Berndt et al. (1989) for the rapid fall in the price-performance ratio of microcomputers themselves.)

Thus the period 1982–1988 was characterized by (1) substantial certainty about the technical characteristics of the most common office microcomputers, especially about their operating system and microprocessor (2) effectively working supply of complementary hardware and software, (3) rapid increases in the number of microcomputers in the workplace and (4) very rapid decreases in the price-performance ratio of microcomputer software and hardware. These forces in the supply of complements affected the development of LAN technology for the office environment in two ways: by encouraging very rapid technical progress in LANs themselves and by influencing the industrial organization of the LAN market.

Desiderata for Office LANs; Rapid Technical Progress

Lefkon (1986) suggested a list of basic user needs for an office LAN:

– Interconnect PCs and intelligent workstations for information sharing and mail or messaging.

- Enable users to access data on mainframes.
- Allow sharing of expensive or scarce resources and peripherals.
- Deliver these services in a secure, easily administered framework.

Above and beyond providing these basic needs, one would expect LANs to experience substantial technical progress given the stable demand environment. This was reflected in falling prices and increased technical and performance capabilities.

It is natural to expect that the rapid decline in the prices of LANs would lead to substantial benefits to acquirers of this technology. To suggest the nature and size of these gains, we consider four case studies from the business press.

The Value of LANs in use

Case I: Rockwell International's Technical Publications Group was burdened with a large backlog as the company began introducing a steady stream of new telephone products. Documentation time often ran up to eight months, and the process of documentation itself was inefficient - writers would shuffle reams of paper and typesetters would type from them. The company wanted to "cut down the overall time by half and to obtain a 35% improvement in staff productivity." (See "Productivity Plus for In-House Publications," *Administrative Management*, October 1985.) After installation of a Xerox 8010 Star LAN with seven workstations

> Information exchange has been speeded and simplified. . .Writers. . .recall documentation from central file servers to make updates an estimated 50% faster. . .

The publication process was streamlined by reducing the number of steps, and simplifying the interface between writers and typesetters.

Case II: The Shearson/Lehman Brothers investment bank in New York had more than 150 unconnected IBM PC ATs and 50 laser printers scattered through six floors. They installed a token-ring ProNet-10 LAN connecting 85 of the PCs to

> encourage the sharing of data, such as spreadsheets and financial analyses, and [of] laser printers. We were also looking for more administrative control and centralization of the PCs.
>
> (Mr. Jude T. Garland, vice president, quoted in Finlay (1986).)

Case III: General Electric's Aircraft Equipment Division in New York wanted to improve productivity by linking various departments' stand-alone computers. A systems manager said,

> Some 80% of the managers already had PCs and they were using "sneakernet", you know, they copied discs and ran around with them. There is a real problem in keeping data timely when you do that.

(See "GE Division Posts Gains with Local Area Network" *The Office*, September 1986, p. 105.) A Fox 10-NET LAN was installed with 66 10-NET nodes; much of the productivity saving in this case came in faster throughput, as well. The end-of-the-month report which previously took 10 days to prepare, could now be done in two days.

Case IV: The Southern Medical Center consisted of three buildings. Approximately 400 Burroughs terminals and printers were spread throughout the buildings. The

Hospital Information System was supported by two Burroughs 7900 mainframes handling patient admitting, drug disbursement, and billing. There was a separate laboratory information system with 150 terminals, printers, and other lab equipment. The medical center installed a centralized star LAN installed to connect all this equipment. Since it ran over twisted pair, the LAN was cheap. "To date, the network shows no measurable delay and is very reliable." ("Case Study: Southern Medical Center," *Datamation*, March 15, 1986, p. 98.)

These case studies show that office LANs provided most of the services suggested by Lefkon's criteria reasonably early in the evolution of their market. The applications are hardly revolutionary, but instead delivered lowered costs by sharing equipment or cutting down duplication of data entry. The passage of information in machine-readable form also seems to have increased the precision with which different workers could interact, and to have shortened lead times for projects.

We believe, on the basis of these case studies, that the falling price of LAN technology has led to a decline in the value of the marginal LAN in use. Thus the social gain to adaption of this technology is likely to be large. Further, this rapid decline in the price of LANs with basic functionality has been paralleled with improvements in the quality of LANs at the high end, another source of social gains. We are not prepared to attempt to quantify this gain, however, by following Bresnahan (1986). The prices of some LAN complements, such as large hard disks and laser printers, have fallen rapidly as well. To a considerable extent, LANs are used to split the fixed costs of these complements across users. Accordingly, LAN benefits depend critically on the level of prices of these complements.

The one desideratum for LANs that has not been well met is the need to deliver services in an easily administered framework. LANs are quite difficult to install, involving considerable supervision and administration. Further, in office environments where there are no specialized computer networking experts, outside consultants have to be brought in to install the LAN. This is expensive, and leaves no one in the organization to administer the functioning of the installed LAN or to rectify the technical problems that may arise later. (See Brenner (1988) for the view that this is a substantial brake on the diffusion of LANs in the office.)

As the dominance of the AT-DOS standard wanes, the importance of the scope of connectivity as a LAN quality attribute will increase. The first aspect of this is the decline of the AT platform standard. LAN vendors selling into complex office environments offer connections between IBM compatible and Macintosh computers, connections to a variety of mainframes, and even, somewhat reluctantly, connections between competing LANs. (See Gengo (1988) for LAN vendors' response to users' demand for inter-LAN interconnect capability.) The second aspect is the present uncertainty about future microcomputer operating systems. The question of what degree of network intelligence will be provided by the platforms' operating systems, what by the LAN vendors, reveals the need for the establishment of new office LAN standards.

Industrial Organization of the Office LAN Market

For an office whose personal computers were largely IBM or IBM compatible, the supply of networking components is vertically disintegrated.[7] The computers themsel-

[7]The analysis of the relationship between vertical structure, technical progress, and the conditions of complementarity can be found in Steinmueller (1987).

ves are supplied by one set of vendors; important peripherals, such as printers, hard disks, etc., by another set. The LAN networking hardware and software is supplied by yet another set of vendors. This gave rise to the "LAN market" as it is viewed in the PC press; independent vendors of connection services hardware and software alone. In particular, no vendor of IBM-compatible computers themselves ("platforms" in LAN parlance) has established itself as a very successful complete-system vendor, selling "turnkey" multi-computer systems. Thus the rents to proprietary standards in the office LAN market are confined to purely connection services, rather than the broader office computing services.

The obvious candidate to sell a proprietary LAN and microcomputer package, perhaps under the old "the system is the solution" slogan, was IBM. IBM's role was in doubt in the early going. For example, it was largely an IBM effort that led to the creation of a competing topology standard to Ethernet at a time when IEEE committees might have settled on Ethernet. (IBM's "token ring" is inconsistent with Ethernet's "bus.") These are very low-level compatibility standards, referring to the way different devices are physically linked together, and to the way that signals can be sent to other devices. Nonetheless, despite repeated rumors, IBM did not attempt to create a proprietary LAN standard for the PC-XT-AT family.

The emergence of this particular form of LAN supply did not occur immediately at the early stages of the market's development. Early on, there were two main market segments for office LANs. The first segment was mainframe and minicomputer oriented. LANs, characterized by distributed intelligence, would replace systems in which users' terminals were "slaves" to "master" multi-user processors. This would permit additional control of data communications by "smart" terminals and would replace the babel of terminal interface protocols (asynchronous ASCII, 3270, etc.). The other expected form was manufacturers of computers that would provide, as a bundled product, processing power, communications, and user workstations.[8] Digital Equipment, AT&T, NCR, and Xerox all made substantial efforts along these lines.

Indeed, some integrated LAN-platform vendors prospered even in the late stages of the LAN market. Apple computer developed its Apple Talk network; Hewlett Packard, HPLAN and HP Officeshare; Sun Microsystems, TOPS. These firms, and their linked networks, represent not just a different form of connection solution. Fundamentally, they are driven by events in the microcomputer market. Apple, with its Macintosh family, was an important dissenter from the DOS/AT standard; HP microcomputers and their connections to HP minis offered a different set of solutions; and SUN, seller of UNIX-based engineering workstations, was an alternate to DOS/AT. Thus, the integrated vendor of platforms and connectivity existed primarily as an offshoot of attempts to establish a second standard for PC platforms themselves.

The main strand of the office LAN market, then, came to consist of companies selling connection services hardware and software alone, not vertically linked to vendors of the other complements. A wide range of performance capability exists at the present time, driven largely by variety in the needs of users for connection services.

Origins of the Office LAN Industry Structure

We have remarked on the vertical disintegration of the office LAN industry structure, in which no attempt is made to construct a proprietary platform-peripheral-

[8]See Way and Bal, 1985 for a description of the industry structure as of that time.

communications standard. Instead, LAN vendors are providers of communications equipment alone, and compete on the basis of price and performance of that equipment. The recent analytical literature on standards, and the state of the supply of complements to office LANs provide an excellent explanation for this industry structure.

First, the existence of a *de facto* standard for one complement (platforms) and the highly competitive supply of other complements (disk drives, laser printers) meant that there was little *need* to coordinate technical developments. Programs, data files, and expensive hardware and software could be expected to be compatible with the AT running DOS. Vendors of LANs could expect, within the IBM-compatible world, to foresee or react to technical developments in these components. The task of the LAN would be to provide connection service among devices that were already fundamentally compatible in the nature of the messages they expected to be exchanging.

Second, there was little *opportunity* during the term of the DOS-AT standard to create a stream of rents associated with a proprietary interface. If such an opportunity had existed, it could have taken either of two forms. First, there could be a proprietary standard based on a network architecture, network interface card, or other purely communications-oriented component. In this case, the source vertically disintegrated structure would be obvious. Second, rents might have accrued to the combined supply of particular computers, software or peripherals and LANs. This strategy had little opportunity because of the rapid technical progress and substantial competition in all branches of IBM-compatible computers. Attempts to establish such rents would be likely to meet imitation, and once again the communications company would find all its rents deriving from the features of its LAN per se.

These circumstances persisted until very recently, when the AT-DOS standard began to wane. Indeed, there is now an open dispute about the provision of network functionality in the office. Operating systems which may replace DOS as dominant, such as OS/2 and UNIX, involve substantial LAN management capability. Data base management systems are now emerging as true distributed-processing applications on networks. (See "Closer to the Promised LAN," *PC World*, June 1988.) There are now, as there were not in the AT/DOS standard era, opportunities for the creation and reaping of rents to the joint provision of LAN connectivity and of software.

4. FACTORY-LANS

Our description of the market for factory-floor LANs can be somewhat terser as we have already introduced the main concepts. Where the office uses LANs on a small scale to connect mostly similar devices, manufacturing uses involve many more dissimilar devices, a larger scale, and faster communications. The economic origins of the demand for LAN capability in production environments are essentially unrelated to the personal computing revolution. Computer-based automation had been progressing for some time in manufacturing. Yet early adoption of computer-based automatic equipment had led to a communications breakdown. Computer aided manufacturing equipment such as programmable controllers, terminals and minicomputers, and computer aided design equipment including terminals and computers came from different vendors and from different schools of thought about data communications. Linking them together involved substantial wiring and programming expense; this expense was often prohibitive. The cliche phrase of the mid-1980's was that "islands of automation" had arisen within the factory but that these islands could not be easily linked. (See Bartik (1985) and Teresko (1986).)

As a technological matter, it was clear that LAN technology was the solution to this problem. The performance requirements were different enough that the market could be essentially independent of the office LAN market. The open question was the nature of the LAN software to be designed and implemented; interface and protocol standards would need to be established. Vendors of assorted types of capital equipment, including at least minicomputers, terminals, programmable controllers, and LANs themselves, would need to accept the standard and comply with it. Finally, manufacturing companies would need to purchase and install the equipment in their factories.

Two very different kinds of standard-setting attempts occurred. The first followed rather naturally from the status quo early 1980's. Influential vendors attempted to establish standards based closely on their own equipment. In particular, Hewlett Packard and DEC became important vendors of proprietary networks. Both firms already had a presence in factory automation as sellers of minicomputers. he second standard-setting attempt took a much less familiar form: large *buyers* attempted to set a protocol standard for factory-LANS. General Motors attempted to establish the Manufacturing Automation Protocol (MAP) as a standard.[9] MAP gained substantial early support from a large number of very large manufacturing companies; Bartik (1985) lists Ford, DuPont, IBM,[10] Kodak, Deere, McDonnell Douglas, and Boeing. These buyers encouraged vendors to provide MAP-compatible manufacturing devices, and they also encouraged the emergence of an independent MAP LAN sector. (See Teresko (1986) for a description of the nature of some of these suppliers of complements.) In a related effort, Boeing pushed TOP, the Technical and Office Protocol.

The goals of these buyers appear to have been twofold. First, they bore the costs of communications incompatibility. They saw the provision of competing, proprietary networking schemes as the source of the "islands of automation" problem. Thus, as with all attempts to set a single industrywide standard, one goal was achieving the social scale economies associated with coordination. Note the contrast to the office LAN situation discussed above. There, at least within the DOS/AT and compatible peripherals world, coordination in the nature of the messages being exchanged was assured by the existence of a dominant "platform" and bus standard. Here, no such standard exists, and the task of coordination fell to the LAN market itself. The achievement of this coordination goal is presumably a public good.

Another goal, however, appears to have been to change the conditions of competition in the market for factory automation equipment. By establishing a single interface standard, the buyers would reduce product differentiation. Further, they would avoid being locked in to any particular vendor's equipment by choosing it early on, and would thus avoid the problem of *ex post* reduction in competition.

Vendors certainly seem to have seen this point. A MAP product manager at

[9]The MAP protocols are consistent with the Open System Interconnect (OSI) "reference model" for computer communications. Broadly speaking, the OSI reference model divides inter-computer communications up into a set of 7 "layers" and delimits *what kinds of* information may be communicated at each layer. It does not specify the "language" for communication, which is what the "protocols" do.

[10]IBM has vaguely supported MAP, even though MAP is inconsistent with IBM's planned proprietary computer interface, the Systems Network Architecture (SNA). Early on, IBM announced several MAP products and an interface between MAP and SNA.'

Hewlett Packard (a competitor of the buyers' standards) characterized MAP and TOP in this way: (See Teresko (1986) p. 48.)

> They are purchase specifications, pure and simple. People talk about a standard. And MAP and TOP relate to communications standards; but, in fact, the goal is to have a specification that could go into every request for a proposal in virtually every company in the country. It would say, 'If you do not supply us solutions based on MAP (or TOP), then we're not going to buy from you.'

Another vendor, who was prepared to be identified only as the "chief executive of a peripherals company" was even blunter:

> The thing (TOP) not only smacks of blackmail, but (TOP) slaps a set of restrictions on the (vendor) industry that hurts our creativity and functionality – two things that have always driven computers. (See "Protecting Their (Computer Companies') Turf," *Industry Week*, November 10, 1986.)

The buyers naturally saw the same issue in a different light: in the same article Boeing's director of MAP/TOP said, "Without TOP, a one-vendor shop has no choice but to stay a one-vendor shop." An official of the MAP/TOP users group thought, "Vendors want to squeeze as much as they can out of those proprietary networks, so it makes sense for them to continue support for those products." (See Tiersten (1988).)

The competing-standards battle that this difference of opinion set off has not yet been resolved. Systems based on interfaces proprietary to a particular vendor appeared to be ahead in the marketplace as late as 1987; approximately five times as many Ethernet-based systems as MAP-based systems were installed that year. In part, this seems to have been driven by the more difficult coordination problem inherent in a multi-vendor environment. MAP has gone through a series of versions, and the changing and improving MAP versions have delayed vendors' commitments to the protocol.[11] The proprietary-protocol vendors, on the other hand, have only an internal coordination problem; their practice is to provide many of the components within the firm. As of mid-1988, the MAP buyers had agreed to "freeze" the MAP protocols until 1994, in the hope of reversing the advantage of the proprietary vendors. The outcome will direct the flow of rents associated with linking together the "factory of the future." It is not unreasonable to expect that flow of rents to be substantial.

There are several lessons to be drawn from the factory-LAN experience. Perhaps the most important lesson is the light these events cast on the role of the large industrial corporation. It is not "small historical accidents" which have influenced the later flow of events here. Instead, very large firms in the relevant industries have attempted to influence the future flow of rents. These very large firms have some advantages; a bandwagon already appears to be rolling if a sponsor like GM is on it. A very large firm can hope to influence expectations and behavior of both its future allies and opponents. Further, the factory environment already has an engineering and MIS department and therefore has "informed buyer" status. This implies the existence of the *buyer* as the possible originator of a competing standard.

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[11]Both MAP-compatible vendors and buyers appear to believe this was the cause. Several of these are quoted in Tiersten (1988). The quote from Michael Kaminski, GM's manager for advanced manufacturing engineering (and the entrepreneur of MAP), is particularly telling:

"They (potential MAP equipment vendors) knew we (GM) were continuing to develop functionality....they decided to wait for it. In a sense, we were the victims of our own enthusiasm. (p. 114)"

Another organizational issue arises, however, when we consider the overall coordination problem involved in creating a new standard. As we suggested, the cooperation of a great many different parties is needed to found a competitive market. The buyers who supported MAP, presumably acting in their own private interest, had to take substantial care to protect the interests of the vendors who were to enter their market. This was at times quite difficult, and reflects the general difficulty of coming to a multiplayer bargain. Each side seeks to establish the outcome that it prefers, ensuring to the extent feasible that the other side is willing to participate. In such an environment, it is natural to expect that not all will go smoothly for the new technology, as parties alternatively leave too much and too little rent on the bargaining table.

It is, however, a rare market in which large enough buyers exist to attempt to direct the standard-setting process, but the buyers are not so large that they cannot bring the process in-house. In many other contexts, a buyer who wished to force a standard would simply have contracted or vertically integrated backward, creating the standard in-house. In this case, two special features were at work. First, the establishment of a communications protocol was a general-purpose technology of very broad scope. The advantages of having many other buyers agree (because of the increased influence with vendors) outweighed any disadvantage from having competitors get access to the technology; most of the other potential buyers were, after all, not GM's competitors.

The sense in which the MAP experience is unique suggests that we treat it as indicative of buyers' desires in standard setting contexts generally. It is not frequent that buyers can reveal their concerns so dramatically, by departing from the normal mechanisms of vendor, committee, or government standard-setting. It is reasonable to presume that the goals of increasing competition, reducing "lock in" to proprietary standards, and encouraging extremely broad interconnect capability are an important part of buyers' motives in other contexts as well. Note that the standard-setting dispute here was, as the theory suggests, fundamentally about the industrial organization of the market. Buyers prefer substantial competition between vendors, who in turn prefer an environment with locked-in buyers.

The final lesson concerns the interaction of market forces and technical ones. We see that here, as generally, both sides of a standardization debate have perfectly valid technical arguments. Opponents of a broad-based standard see coordination on any particular standard as cutting off the exploration of valuable technical routes, and emphasize the need to tailor particular solutions to particular problems. Proponents of an industrywide standard see the technical advantages of coordination. Of course, neither of these is determinative, and the equilibrium process in which different views are allied with different willingness to accept risk determines the actual outcome.

5. CONCLUDING REMARKS

We have emphasized the role of suppliers of complements in the standard-setting process, in part because of the contrast factory LAN and office LAN experiences offer in this regard. In the office LAN case, no supplier of complementary inputs had a plausible opportunity to establish a *de facto* standard which linked proprietary technology to an interface standard. In the factory LAN market, by contrast, there were two different attempts to control the standardization rents. Owners of proprietary computer technology attempted to establish proprietary network standards as well, thereby locking in their customers. Buyers sought to reduce product differentiation, and thereby market power, by establishing an industrywide standard. The LAN experience in the office and factory does underscore two major themes of the analytical literature; complementarity and endogenous industry structure.

The other analytical issue clearly raised by the contrast between these two closely related markets is organizational. We normally think of communications services as we think of most new general purpose technologies; they are produced "on spec" by vendors, and buyers choose whether to take or leave them. In the case of factory LANs, large, sophisticated buyers attempted to establish the nature of the market. Their experience leads immediately to our other organizational point. It is surprisingly difficult to coordinate a great many different firms to move forward in a mutually advantageous way. That the market did this in an apparently effortless way in the office computing environment, while the proposers of MAP had substantial difficulty with it in the factory computing environment, is a tribute to the power of market forces.

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