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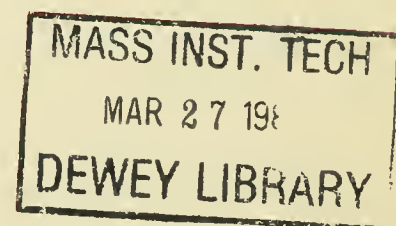


STANDARDS SETTING
FOR
COMPUTER COMMUNICATION:
THE CASE OF X.25

MARVIN A. SIRBU
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SEPTEMBER 1984

CISR WP #117
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Standards Setting for Computer Communication: The Case of X.25

Marvin A. Sirbu^{*} and
Laurence E. Zwimpfer^{**}

1. Introduction

The first international meeting to set standards for data communications was held in Paris in 1865, to discuss interconnection of telegraph systems. Since that time, an elaborate network of institutions and procedures have grown up which attempt to coordinate the development of standards for telecommunications in general and data communications in particular. The convergence of computers and communications technology in the 1970s, coupled with changes in the political and economic environment of these industries have forced dramatic changes in both the role of standards, and the processes by which standards are developed. In this paper, we shall outline the broad directions of these changes, and illustrate them with a detailed examination of the development of the packet switching standard, X.25.

2. The Nature and Function of Standards

Standards are of many types: the IBM Personal Computer Technical Reference defines a *de facto* standard for personal computers. Bell Communications Research procurement specifications represent another type of standards document. More typically, however, when we think of standards we think of formal documents certified by a self-defined standards making body. Groups engaged in formal standards setting include international agencies, national standards bodies, professional associations, trade associations, government regulatory agencies and cabinet departments and bureaus. Standards may, but usually do not, have the force of law; generally they represent voluntary agreements among producers.

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While a standard can be thought of as a document, it also involves a set of behaviors and a process. Firms may build compatible devices though what is required for compatibility is nowhere written down. Conversely, because a standard has been reduced to writing does not mean that firms have agreed to abide by it. Standardization is the *process* of developing the consensus among firms and the patterns of behavior which will achieve the ultimate goals of a standard, not just the production of a document.

In the area of computers and communications there are two principal functions of standards: compatibility and variety reduction¹. Compatibility or interchangeability standards are necessary for complementary products, manufactured by different producers, to work together. Railroad gauges and boxcar axles, light bulbs and sockets, data terminal equipment (DTE) and data circuit-terminating equipment (DCE) will not work together unless they are compatible.

Variety reduction, limiting the number of versions of a product, may be essential for producers to achieve potential economies of scale. A local area network (LAN) standard may be necessary to induce chipmakers to invest in VLSI implementations of a local network protocol. Without a standard, they would be skeptical of achieving sufficient production volumes to justify the front end investment in chip design. Variety reduction can also lead to economies of stocking and distribution through reduced inventory holdings². The absence of a standard for 5 1/4 inch floppy disks means that software dealers must stock programs in multiple versions for each possible system.

While the compatibility and variety reduction functions are often closely related, they are not the same. Maximum compatibility would require a single local area network protocol; but available economies of scale in chip manufacturing may be achievable where the same chip can be used for two different protocols. This is precisely what Intel proposes to do in supporting both Ethernet and Mirlan LANs with the same chip set³.

In the information and communications arenas, compatibility has two aspects:

1. the *functions or services* provided by the two devices must be compatible; and
2. the *procedures* used to provide the functions or services must be compatible.

Identical functions provided using different procedures can often be made compatible through a simple software conversion. If the functions provided are different, an exact translation may not be possible. Additional functionality usually means higher costs, either for the end equipment or for research and development. Functionality may also be critical to achieving market acceptance by the end user. As a consequence, arguments over what functionality to include in a standard are usually the most contentious.

3. Economic Theory of Standards

The economic motivation for standards will be different depending upon the goal of the standard -- compatibility or variety reduction -- and depending upon the economic positions of the participants in the standards process.

In the absence of economies of scale in production or of inventory, there is no incentive to seek variety reduction standards. Similarly, there will be a demand for compatibility standards only if users wish to communicate or share information with a wide range of other users, and if the costs of translation, or multiple basic equipment sets, is significant.

The market structure of both buyers and sellers is clearly relevant to the incentives for standardization. Users often pay dearly for the absence of standards, thus, they should be the principal supporters of standardization. Buyers may be fragmented, however, and unable to coordinate their demands. Where buyers are few and powerful, they can more easily exert pressure on sellers to standardize, or force standards by coordinating their purchase specifications. Concentration among buyers should thus favor standardization.

Communications networks have significant externalities: the more other people one can communicate with, the more valuable is the network. Where these externalities translate into increased demand for equipment which can access a larger portfolio, sellers have an incentive to standardize in order to increase the total size of the market.

Where sellers are fragmented, it may be difficult to coordinate the development of standards.

Where there is one dominant firm and many small ones, we can expect de facto standards to be set by the dominant firm (absent patent, trade secret or copyright protection which inhibits copying the dominant firm)⁴. Where sellers are few but of equal size, compatibility standards would act to reduce market power, and thus may be resisted. Integrated sellers who produce both primary and secondary products may resist standardization since it allows entry to competitors who produce only one of two conjoint products.

The coalescence of firms around a standard is a positive feedback process which results from the positive externalities of adopting the standard which allows communications with the largest number of other users. Thus, smaller firms are led to fall in behind the standard of whichever firm or group of firms establishes the largest early following.

4. Standards Setting Processes in Computers and Telecommunications

In the mid 1970s, the structures of the telecommunications and computer industries differed greatly. These differences included the legal charter of the participants; their economic motivations; the characteristics of the technology; and the characteristics of their technical and managerial employees. All of these differences contributed to quite different patterns of behavior with respect to standards.

4.1. Telecommunications

Telecommunication services have traditionally been provided by government agencies -- Ministries of Posts Telegraph and Telephone (PTTs) --, by nationalized firms such as Nippon Telephone and Telegraph, or by regulated private monopolies such as AT&T. Until quite recently, the focus of these firms has been on the extension of basic telephone service to an ever greater fraction of the population. Thus, from 1976 to 1983, the number of telephones in France increased from 7 million to 24 million. In most countries there was an unmet backlog of demand for basic service; consequently, telephone authorities have been more concerned with increasing supply than designing and marketing new products or services. Technological change was confined primarily to the process of providing telecommunication services and not to the service product.

Telecommunication operations are characterized by large capital investments in highly reliable, long-lived equipment. Telecommunications equipment is often depreciated over a period of 20-40 years, and thus new technologies are introduced slowly. There is an absolute requirement that new equipment continue to work with the old.

Because of the specialist character of telecommunication systems and the monopoly position of most network operators, staff mobility at the technical and management levels has been low; most would in fact spend all their working life with the same organization. Seniority is an important element for promotion and therefore middle level technical managers are typically over 40.

As monopoly providers of telecommunication services, most have absolute authority to set their own standards at the national level. At the international level, they meet together as members of the International Telecommunication Union (ITU) to decide on interconnection arrangements between national networks. The manufacturers who supply equipment to the telecommunication carriers also participate but they have no voting power. Technical standards (or Recommendations as they are formally known) are set by the International Consultative Committee for Telegraph and Telephone (CCITT), a permanent organ of the ITU. The CCITT meets every four years to agree on a program of work for its specialized study groups and approve new Recommendations. Detailed technical work is carried out by Working Parties or Special Rapporteurs.

Telecommunication standardization processes have traditionally been very stable, based on many decades of first-hand experience in international agreement-making. The process has been well-defined and understood by the participants⁵. The participants have also been a relatively homogeneous tight-knit group with a rather conservative outlook. The absolute necessity for international standards to permit the interconnection of national networks has been a strong motivating factor in obtaining complete consensus on the standards developed, although there have been cases when some participants have placed more value on national goals than international ones, (e.g. color television standards⁶). Typically, standards have only been approved after they have been implemented and tested; that is, the standardization process has relied heavily on compromises

based on established de facto standards⁷. However, the process has not been able to cope well with situations in which participants already have a substantial commitment to a particular de facto standard: for example, the divergent U.S. and European standards for PCM.

4.2. The Computer Industry

The computer industry in the mid 1970s presented a completely different picture. Instead of stable, conservative, national monopolies, the computer industry was a dynamic, rapidly changing industry dominated by a few large multinationals. The industry has been highly innovative and rapidly changes its product mix. The industry's dominant firm, IBM rose to its position through its emphasis on marketing, rather than process technology. Most computer equipment has had a design life of 5-10 years; the rapid advances in microelectronic miniaturization and the corresponding rapid decline in costs has created a pressure on users to regularly upgrade their equipment. Unlike the telecommunication industry, the infrastructure required to support a computer system is relatively small. The people involved are also typically much younger than in the telecommunication industry (20-40 age group) and as a group have a much higher mobility --partly because of their age but also because they possess more marketable skills.

Attempts at standards setting in the computer industry have been diffused and largely ineffectual. At the national level, standards have generally been coordinated by a single organization (e.g. The American National Standards Institute (ANSI) in the United States) but other organizations are encouraged to do the actual standards development work, including trade associations (e.g. in the United States, the Electronic Industries Association (EIA)), and professional groups (e.g. the Institute of Electrical and Electronic Engineers (IEEE)). Large computer users (e.g. the Federal Government in the United States acting through the National Bureau of Standards) have also taken an active interest in the development of standards, and where necessary, have adopted their own standards.

Because the computer industry has been so dominated by IBM, consensus standards-setting procedures have been relatively unsuccessful. Only when there has been pressure from a large user (typically the government) has progress been made.⁴ Because IBM has been a full line producer of

both basic and complementary products, it has had little incentive to support standards which would have enabled smaller competitors to attack it in piecemeal fashion. Also, because computers in the early years operated primarily as stand-alone devices there was less incentive for standardization. Users could achieve internal standardization by buying from a single vendor; standardization on a larger scale brought few additional advantages. Rapid technological change also undermined efforts at standardization. For example, in 1961 IBM was promoting its 6 bit code (BCD) as a US standard interchange code, but only four years later had changed to support an 8-bit code (EBCDIC).

4.3. Changing Industry Structure and Its Effect on Standardization

Major changes in both technology and regulation altered dramatically the industry structure in both computers and communications during the 1970s. These changes affected the motivations for achieving data communication standards, and had a profound impact on the development of X.25.

Beginning with the Carterphone decision in 1968 and the Specialized Common Carrier decision in 1971, the U.S. began opening the telecommunications industry to competition. Within a few years literally hundreds of companies would be offering a dazzling variety of customer premises equipment -- including computer terminals and modems -- while others would promise a host of new network services, including all digital facilities. This influx of new entrants challenged AT&T's traditional dominance of the U.S.' telecommunication standards process.

The computer industry also was witnessing a period of increased competition. Under the threat of an anti-trust suit filed in 1969, and because of its failure to foresee the importance of the minicomputer market, IBM had lost share to a new group of companies such as Digital Equipment Corporation, Data General, and Prime. With continued growth, the industry also began to shift away from the model of large computer utilities based on hand crafted mainframes towards interconnected networks of hundred or even thousands of mass produced machines. This transformation, made possible by the spectacular successes in microelectronics, made even more imperative the need for standards: not only for compatibility, but to achieve the economies of scale offered by VLSI technology.

VLSI technology allows extremely complex devices to be manufactured at very low unit cost; the challenge is to find a design needed in sufficient quantity to justify the front-end investments. Standards help create and define such needs. Once etched in silicon, however, standards are more difficult to change. Complex software -- such as for computer networking -- exhibits similar economic characteristics: large design costs and low reproduction costs. Unlike hardware, however, software based standards are easier to modify and evolve, posing problems in the stability of standards once they are codified.

These changes in technology and regulation have affected the standards process in several ways. The shift from standards primarily for reasons of compatibility towards standards for variety reduction altered the motivations of the participants. The need to define a standard in order to *create* a market, as opposed to interconnect two national markets leads to:

1. pressures to accelerate the standards process for commercial reasons;
2. definition of standards in parallel with research and development on the underlying technology;
3. increased risks of problems in the resultant standards due to hasty development; and
4. the absence of market experience making difficult the resolution of controversies over the appropriate level of functionality to incorporate in the standard.

Finally, deregulation and the convergence of computers and communications has vastly increased the number of players. The larger set of needs to be satisfied increases the risk that either: a) no standard will be agreed to, or b) some significant group of users will find the resulting standard unacceptable.

Thus, as a result of deregulation in the telecommunications industry and a shift towards mass production and increased competition in computers, the standards processes in these industries came under heavy pressure just as packet networks were being developed.

5. Computer Communications and Packet Switching

Early computer systems were quite independent of each other and therefore the development of the industry was not constrained by the absence of standards. Even early time-sharing computer systems with remote terminals were still relatively self-contained: typically both the central processor and the remote terminals would be supplied by the same manufacturer (or equipment supplied by other manufacturers would copy the de facto standard of the principal supplier). However, some standards were required to interface computers with the communications network, e.g. modems. The single critical need for standards was at the interface between the computer terminal and the communications line which linked remote terminals to the computer. Through their control over "foreign attachments" to the network, the telephone administrations were in a position to determine standards for the modems which converted digital bitstreams into analog signals suitable for the voice network.

But voice telephone circuits are costly to the data communications user and totally inadequate for high speed, error-free data communications. During the late 1960s, the concept of packet switching emerged as a solution to the problem of providing efficient, error-free service to computers sending "bursty" traffic. Packet switching systems transmit data by means of addressed packets, i.e. groups of binary digits which include both data and call control information. These packets occupy the transmission channel for the duration of the transmission of the packet only. The channel then becomes available for use by packets being transferred between different data terminal equipment. Packet switching became economically viable largely because the cost of computer processing needed to create, process, and switch packets was declining at a much faster rate than that of communications channels. Thus, it became cost effective to use computer-based switching to make more efficient use of the channel.

There are two distinctly different ways to organize the provision of packet switching service: *connection-oriented* or *connectionless*, often referred to as *virtual circuits* vs *datagrams*.

- *Datagram service*. In a "connectionless" datagram network, each packet carries the full address of the destination and is routed independently from the origin to destination

terminal. As a result, packets may arrive out of sequence at the destination. Others may be corrupted in transit by errors, or even lost altogether. In a connectionless network, it is the responsibility of the endpoints to resequence packets or request retransmission of packets damaged in transit.

- *Virtual circuit service* is the logical equivalent of a physical circuit, or connection, between the source terminal and destination terminal. An originating terminal starts by sending a call origination packet which specifies the destination to which subsequent data packets are to be sent. The call is assigned a short logical call number which can be used to specify where to send subsequent packets. The network takes responsibility for insuring that packets arrive in the correct sequence -- as they would on a "circuit" -- and for requesting retransmission of lost packets. At the end of a virtual call, a clearing packet takes down the virtual circuit. As with leased lines in the telephone network, customers can be assigned "permanent virtual circuits" which are always in place.

As we shall see later, debates over virtual circuit versus datagram service played an important role in the development of packet network standards.*

5.1. Standards for Computer Networks

The exchange of data over a computer network requires agreement at many levels, from the physical interconnection of the computer to the communication line to agreements on the meaning of the bits exchanged between computers at opposite ends of the network. Early in the development of packet networks it was recognized that a standard would be needed to define how a computer or terminal should connect to the network. This interface, between DTEs and DCEs, would mark the boundary between equipment provided by the carrier and equipment provided by the user, or the computer manufacturer.

The development of standards for this interface provides a dramatic illustration of the differences in process and motivations for standardization in the computer and the telecommunications industries.

* For a further discussion of the merits of virtual circuits versus datagrams see ^{8, 9, 10, 11}.

6. A Case Study of X.25

The revolution in computers and communications has been so rapid and computer communication networks are today so widespread that it seems difficult to imagine that the ARPANET first demonstrated the possibilities of packet switching a mere 15 years ago. Indeed, what is striking about the history of X.25 are the doubts which prevailed throughout the process as to the very need for public packet networks, and the possibilities of developing a successful standard. While today X.25 can be viewed as a successful standard, there were, as we shall see, many rough spots along the way.

6.1. X.25 gets on the standards agenda

The need for special systems and standards for data communications was first recognized by the CCITT with the creation of a Working Party in the late 1950s. At the 1960 Plenary Assembly, the Data Transmission Working Party was elevated to full study group status, and by 1964, the new study group had produced a set of recommendations dealing with data transmission over the telephone network. At the 1968 Plenary a Joint Working Party¹² was created to investigate the possibilities of new networks that might be wholly dedicated to data transmission services.

By 1972, the Working Party had become Study Group VII (New Networks for Data Transmission) and had outlined a program of 23 points under the general Question: "What general characteristics should be standardized to permit international data communications over public data networks?"¹³ Most of the discussion within NRD prior to 1972 had concerned circuit switched public data networks; between 1968 and 1972 several PTTs had announced their intention to build such networks.¹⁴ Only one of the 23 points, Question C, dealt with packet switching: "Should the packet-mode of operation be provided on public data networks, and if so how should it be implemented?"¹³ By July of 1974 a Special Rapporteur had been appointed for question C and a program of study established.

¹² NRD - Nouveau Réseau de Données

6.2. Early packet switched networks

By 1972, when the CCITT was still asking whether there should even be public packet switching networks, there were numerous private or experimental networks already in operation: ARPANET in the U.S.¹⁵, NPL in the UK, and the international airline reservation network, SITA.¹⁶ Two public networks, RETD in Spain and the Tymnet network in the U.S.¹⁷ were also in operation.

Most telephone administrations, however, expected circuit switched digital networks, carrying both voice and data, to meet the demand for data services and, ultimately, to be far more economical than building a separate packet network just for data. Voice communications generated by far the greater amount of traffic, and the idea of packet networks as the dominant technology for carrying both voice and data was -- as it still is -- viewed as speculative.

In October 1972, the ARPANET was demonstrated at the first International Conference on Computer Communications, and, according to Larry Roberts, then head of DARPA, converted many skeptics into believers.¹⁸ However, there was still a great deal of uncertainty among PTTs concerning the wisdom of establishing packet services: standards would take too long to develop and computer manufacturers would be reluctant to make the necessary changes to their products to support a standard network interface.

Such skepticism had not deterred first Packet Communications Inc and then Telenet (a subsidiary of ARPANET builders, Bolt Beranek and Newman) from seeking authority in the US to establish public packet networks. By April 1974, both had received approval, though PCI soon dropped out when it had trouble raising capital.

In France, a decision to build a public packet switched network (TRANSPAC) was made in November 1973,¹⁹ based on experience gained with an experimental network called RCP.²⁰ In Canada, a trans-continental all digital private line service was introduced in 1973 by the Computer Communications Group of the Trans-Canada Telephone System (TCTS).²¹ However, private line service was recognized to be uneconomic for low volume users. TCTS began planning in 1973 for a packet switched service, DATAPAC, which was announced in October, 1974.²² In the UK, the British

Post Office awarded a contract to Ferranti Ltd. in August 1973 for an experimental packet service, EPSS.²³

There was also considerable interest in two packet networks being developed jointly in Europe: The European Informatics Network (EIN) and EURONET. EIN was driven by the research community,²⁴ while EURONET was a project of the PTTs, designed to make science information databases throughout Europe more easily accessible. A contract for EIN was let at the end of 1974, and for EURONET at the end of 1975.

In 1971 Japan's NTT had begun research on an integrated circuit/packet switching system, DDX-1, which was installed and tested by NTT in 1974.²⁵ Its successor, DDX-2, for which research began in 1973, was based on separate packet and circuit switched networks.²⁶ Needing a standard DTE/DCE interface for DDX-2²⁷, NTT took an active interest in the work of the Rapporteur's Group, eventually submitting 15 contributions, and attending all of the Rapporteur's meetings.

6.3. Commercial Pressure for a Standard

In November of 1974, at the third meeting of the Rapporteur's group, attention finally moved past whether there should be packet nets to the question of a standard for the interface between the network and the computers which would use it. Without such a standard, a would-be vendor of packet network service would have to provide custom software and hardware for every brand of computer that wanted to use the network. With such a standard, the computer vendors themselves might eventually provide the necessary capability for their products to use packet networks. The Canadians in particular were anxious to see a standard defined. While DATAPAC was not scheduled to come into operation until 1975, design decisions had to be made in 1974. Moreover, the growing interest in packet switching exhibited at the second ICCC in 1974 suggested that there would be many networks by the end of the subsequent CCITT study period in 1980. If a standard could not be agreed before the 1976 Plenary, then by 1980, each network would have been firmly committed to its own design, and the adoption of a new international standard would be both politically and economically unacceptable.

Thus, Dave Horton, in his role as Assistant Vice-President for Planning of the Computer Communications Group in TCTS began an international lobbying effort to press for the adoption of an interface standard. Horton realized that in order to influence the CCITT, he would first have to obtain support from other telecommunications administrations. A joint contribution would be more likely to gain acceptance than one submitted by a single administration. Horton began the process by issuing a glossy-covered specification of the proposed DATAPAC service and circulating it widely.²⁸

6.4. Virtual Circuits Versus Datagrams

The TCTS draft called for a standard based on a datagram mode of operation. However, Telenet was implementing a virtual circuit network, and the French RCP was also a virtual circuit design. If there was to be a standard, it was clear to Horton that agreement on this fundamental design choice was imperative.

Roberts, by now President of Telenet, favored virtual circuit service, largely for economic reasons. Simply routing packets represents only 10% of the value added of a packet network; providing virtual circuit service and other interface facilities would be the major contribution. With a datagram interface, the computer processing to resequence packets could be provided by the end user. A virtual circuit interface would force the customer to obtain -- and pay for -- these services from the carrier.⁹

Technical arguments for choosing virtual circuit service were advanced as well. Roberts argued that a datagram network places the various network control functions--e.g. error control, flow control, packet sequencing--in the hands of the end user. As a result, the network can respond to overload situations only by throttling all traffic from an entire host, even if it is only one virtual circuit that is generating the overload condition.¹⁸

Datagram proponents argued that the overhead involved in setting up a virtual circuit was wasted for simple point-of-sale, or automatic teller transactions where one packet in each direction might be all that is required. Moreover, they argued, no matter how reliable the virtual circuit service is, users will feel they must protect themselves against the possibility of network errors by duplicating in the

end computers much of the error correcting and packet sequencing facilities provided as part of a virtual circuit service. Finally, packet voice suffers less from an occasional lost or damaged packet in a datagram network than it does from the uncertainties in delivery delay associated with virtual circuits.²⁹

Faced with these arguments, and recognizing that Telenet and the French PTT were more committed to their respective implementations, TCTS agreed to align DATAPAC by providing virtual call service. However, DATAPAC retained the datagram mode as the underlying transport mechanism.³⁰

6.5. Formal and informal processes

In January of 1975, a group from TCTS traveled to London, Paris and Madrid to meet with their counterparts in the PTTs, and discuss the DATAPAC proposal. This was followed by a series of informal meetings during 1975, mainly involving TCTS and the French PTT, aimed at developing a draft standard. Although both groups were also participating in the formal CCITT meetings (See Table 6-1 for a chronology of working group meetings), much of the drafting work was carried out informally. A total of ten such informal meetings, some lasting as long as a week were held in 1975. By the end of the year, Telenet and the BPO were also drawn in to these informal meetings. Also by this time, interest in packet nets had grown to where Rapporteur's Group meetings were drawing 40-50 people.

The same individuals were also representing their organizations in the Data Communications Subcommittee of the International Standards Organization's TC97, as well as in ANSI X3S37. Meetings of these groups provided additional settings for discussing X.25.

6.6. National Delegations and Standing in the CCITT

As a treaty organization, it is States -- and not companies -- that have official standing in the ITU. In the US, the Departments of State and Commerce organize Study Groups of US firms to formulate a national position for CCITT meetings. For all its enthusiasm, Telenet could not speak for the US, and

Table 6-1: Chronology of Formal CCITT Meetings
Related to X.25

Date	Meeting
December 1972	5th CCITT Plenary Assembly (Geneva)
January 1974	SG VII First Meeting Rapporteur on Packet Switching - First Meeting
August 1974	Rapporteur on Packet Switching - Second Meeting
November 1974	Rapporteur on Packet Switching - Third Meeting
March 1975	Rapporteur on Packet Switching - Informal Meeting
May 1975	Rapporteur on Packet Switching - Fourth Meeting SG VII Second Meeting
September 1975	Rapporteur on Packet Switching - Fifth Meeting
February 1976	SG VII Final Meeting
September 1976	6th CCITT Plenary Assembly (Geneva)
November 1976	Interim Rapporteur on Packet Switching
April 1977	SG VII First Meeting
April 1978	SG VII Second Meeting
April 1979	SG VII Third Meeting
February 1980	SG VII Final Meeting
November 1980	7th CCITT Plenary Assembly (Geneva)

could not, on its own, advance its views directly. Indeed, until it received approval as a recognized public carrier from the FCC in April 1974, it had no right even to attend CCITT meetings. Throughout 1974 and 1975 the US official position -- dominated by the skeptical views of AT&T -- was that development and approval of an interface standard for packet switching was premature.

TCTS experienced similar problems in obtaining support from the official representative organization for the CCITT in Canada, the Canadian Telecommunications Carriers Association (CTCA). TCTS's proposals were opposed by a competitor, CNCP, who considered that the rapid development of a standard would not be in their business interest; consequently, TCTS's views could not be presented as the Canadian position. Thus, while Telenet and TCTS played key roles in drafting the eventual standard, the drafts had to be submitted as national contributions from France and the UK, whose positions were determined solely by their respective PTTs.

In 1974 the International Federation for Information Processing was granted category (d) membership in the CCITT. This meant that representatives of the IFIP Network¹ Working Group, 6.1, could participate in the CCITT in an advisory capacity. IFIP did submit a number of written contributions, and strongly supported the inclusion of a datagram service, but representatives to the CCITT meetings quickly discovered that they were quite powerless in the CCITT forum.

6.7. X.25 (1976)

A first draft of X.25 was finally prepared by an informal drafting party in Ottawa in March, 1975 -- work which was subsequently confirmed in the May 1975 formal Rapporteur's meeting. Numerous informal meetings during the summer led to 8 written contributions to the September Rapporteur's meeting, the last scheduled meeting of the 1973-76 study period.

Although there were a full 12 months remaining in the study period after September there would be no opportunity for any more meetings at the Rapporteur level. The results of the meeting needed to be translated into the three working languages used by the CCITT and distributed before the final meeting of SG VII in February 1976. After the February SG VII meeting, there would be no opportunity for further change before formal ratification at the September 1976 CCITT Plenary Assembly. Thus the final meeting of the Rapporteur's Group was crucial: under traditional CCITT procedures, the decisions of this meeting would determine whether or not a standard would be adopted in 1976.

By the end of the September Rapporteur's meeting, however, there were still numerous unresolved issues: e.g. packet lengths, packet length indicators, call progress and advisory signals, "more data" indicator for virtual calls, datagram and virtual call flow control mechanisms.³¹ Furthermore, the datagram/virtual call issue remained unresolved. Roberts had proposed to the meeting that the datagram classification be changed from "essential" to "additional." He was supported by representatives from France and TCTS. However, representatives from NTT, ISO, ECMA, USA and CTCA spoke against hasty action; as a result the point was left open. The final report of the Rapporteur's meeting made it seem doubtful that a standard would be ready for adoption by SG VII.

Immediately following the September 1975 Rapporteur's meeting (which had lasted two days),

TCTS, the French PTT and Larry Roberts spent a further week in Geneva redrafting the X.25 proposal. In mid-October, TCTS and Telenet met for further discussions. At the end of October, Remi Després from the French PTT attended a meeting of ISO TC/97/SC6 in Washington, D.C. While Després was in Washington, Roberts seized on the opportunity to arrange a further X.25 meeting.

A key issue in their discussion was flow control. Després supported flow control with local significance only (DTE-DCE); Roberts supported an end-to-end flow control significance (DTE-DTE). Després also supported an explicit credit flow control scheme while Roberts supported window rotation.³² This conflict arose because of different implementations in the Telenet and RCP networks. Initial attempts at resolving these differences failed, but with assistance from Anthony Rybczynski of TCTS a compromise was eventually reached by disguising some of the differences of opinion in the wording of the draft recommendation; e.g. local flow control was mandated but end-to-end flow control was acceptable if desired by individual network providers. Everyone knew that such a loose specification would create problems when attempts were made to interconnect different networks in the future, but all were prepared to pay this price in the interests of getting the agreed portions of X.25 accepted.

The result of this meeting was a draft recommendation that TCTS, Telenet, the French PTT and the BPO were prepared to support. That this agreement was tantamount to a standard was reflected in an article drafted by Rybczynski (TCTS), Wessler (Telenet), Després (French PTT) and Wedlake (BPO) for the 1976 AFIPS National Computer Conference. Submitting their paper even before the SG VII meeting in February they described the draft standard as a *fait accompli*.³³

Thus, by the end of 1975, with the exception of Spain, every administration and carrier who had either already established a public packet network or had made a commitment to do so was prepared to support the proposed X.25 standard. The Spanish RETD network had been in operation for almost five years and its national traffic continued to increase without the benefit of a standard DTE/DCE interface. Spain felt the development of X.25 was an "unstable study" and therefore had no intention of supporting it in their network.

Despite acceptance by the leading carriers, the draft still needed to be ratified by the 200 members from 20 countries represented in SG VII. During debate on the draft proposal many of the known problems surfaced. The official US delegation was a particularly vocal critic; the US position was that no standard should be accepted which had obvious technical flaws. The technical points of conflict were not resolved, but a document was agreed to after the US delegation, under pressure from France, agreed to stop challenging the proposal. Consent by the U.S. was understood to be in return for French cooperation on unrelated issues at the Plenary. In September 1976 at the CCITT Plenary, the eleven recommendations of SG VII -- including X.25 -- were adopted unanimously, thus completing the formal process.

6.8. Problems and Revisions

Adoption of X.25(1976) by the CCITT did not bring about immediate widespread support. Some saw it as little more than an "advertisement for a standard."³⁴ The participants themselves knew there were many ambiguities and unresolved issues. Two of these were of particular importance: alignment of the link level of X.25 with the HDLC standard being developed by ISO; and datagram service.

X.25 had been developed using a draft ISO HDLC procedure at the link level. The draft ISO procedure was subsequently rejected when put to letter ballot and a modified proposal developed. By early 1977, the ISO had still not reached agreement on the portion of HDLC dealing with symmetrical and balanced classes of procedures which were of most interest to X.25³⁵

In the *unbalanced* class of procedure, one station (designated the primary) has total responsibility for control of the link. This class had been strongly supported by IBM whose Systems Network Architecture was, at that time, designed to rely on a large central mainframe controlling dependent terminals. Over the opposition of IBM, this class had been extended to permit an *asynchronous response mode* (ARM) in which a secondary may transmit without receiving explicit permission from the primary. The LAP in X.25(1976) had been based on the ARM proposal. However, during balloting potential deadlock problems were detected with the proposal³⁶, and a new *balanced* class of

procedures was developed. For this class, no distinction is made between primary and secondary stations, thus giving both stations equal control over the link. A version of this mode, known as *asynchronous balanced mode* (ABM) was proposed as a revised link access procedure for X.25, or LAPB.

To avoid the risk of further inconsistencies between CCITT and ISO standards making, a joint meeting of CCITT SG VII experts and ISO TC/97 met in April 1977 to review their differences. Eventually a compromise "mutually objectionable to both parties,"³⁷ was reached.

Despite the compromise, the earlier LAP standard was on the books as the official X.25 link access protocol. There was a danger that both network developers and DTE vendors would continue implementing the old LAP protocol, leading to two camps with incompatible standards. Already TCTS had adopted LAP in the DATAPAC network and by early 1977 had proceeded much too far in implementing its network to convert immediately to LAPB. To make clear that LAPB was the new preferred standard, a newly adopted CCITT letter ballot procedure for obtaining "Provisional Approval of Draft Recommendations" between Plenaries was used to ratify LAPB; fifteen administrations approved and three abstained.³⁸

At the February 1976 SG VII meeting it had been agreed to hold datagrams over for further study.³⁹ At the first meeting of SG VII in 1977, the participants examined a proposal from Japan for a *fast-select* service.^{40, 41} The fast-select facility would allow the inclusion of user data in the call set up and call disconnect packets. Thus for small quantities of data -- e.g. transaction data -- the fast select facility would provide for a simple two packet exchange, much like a datagram service. However, fast select still requires the network to incur the overhead of virtual circuit set-up.

Support for inclusion of a datagram service in X.25 came primarily from IFIP Working Group 6.1,⁴² and ANSI X3S37.^{43, 44} IFIP represented the scientific community and their interest in a network service that provided maximum flexibility to the user. The ANSI position was formulated by a subgroup whose members represented ARPA, NCR, Xerox and Western Union. Their support for datagram service was couched in economic terms: *i.e.* that datagram service would be far more cost

effective for short transaction type traffic than would be virtual circuits. To buttress their position they conducted and published a survey of users and vendors on the desirability of a datagram interface,⁴⁵ and rallied additional support in ISO TC97/SC6. The French countered with a proposal to use permanent virtual circuits as a means to provide a low-overhead data exchange capability.

In February 1980, SG VII adopted a revised version of X.25 (X.25(1980)) which included datagram service and fast select as "additional," or optional services as opposed to "essential" parts of the standard. Inclusion of a datagram specification has turned out to be an empty gesture. In the absence of any obligation to implement datagram service, not a single public packet network operator has done so. X.25(1984) calls for the datagram option to be dropped altogether.⁴⁶ The fast select option has been implemented only by NTT.⁴⁷

7. Lessons From X.25

Louis Pouzin has described the X.25 standardization process as a "well engineered political coup".⁴⁸

A small, highly motivated group of packet switching carriers developed a new standard in record-breaking time and persuaded a very conservative standards organization, the CCITT, to accept its proposal. The process was 'well engineered' with respect to its timing and the mix of formal and informal processes used. In 1975, there were a number of imminent public packet networks; adoption of a standard before implementation seemed to make good sense. X.25 was 'political' in the sense that the most important issues at stake had little to do with technical compatibility, the usual motivation for international telecommunication standardization. A DTE/DCE standard was needed to persuade computer mainframe and computer terminal manufacturers to produce equipment compatible with the emerging packet networks. A standard was also required so that telecommunication network providers could secure their claim for a share in the rapidly growing data communication market. X.25 was a 'coup' in the sense that just when the institutional processes (the Rapporteur's group) seemed to be foundering, the informal group suddenly produced a completed draft proposal supported by a number of telecommunication administrations and carriers. Furthermore, the group succeeded in gaining the approval of the CCITT.

7.1. Evaluating X.25

Before we can draw any conclusions from the case of X.25 for other standards efforts, we must first establish whether or not X.25 can be judged a "successful" standard. Success can be measured in two ways: first, by the extent of use of the standard; and second, by a more subjective assessment of "technical quality".

Over 30 countries have public packet switching services -- all X.25 compatible -- while only a dozen countries offer circuit switched digital services.⁴⁶ Most administrations were able to take advantage of the revised X.25 proposals developed during the 1977-1980 CCITT study period; only four networks implemented the 1976 version of X.25, and it took until 1983 for Telenet to fully convert to X.25 (1980).

An important goal of the network providers was to induce terminal and computer equipment manufacturers to develop X.25 compatible products: in this they have been successful. A survey of 60 computer and terminal manufacturers made by TCTS in 1978 showed 25 already committed to supporting X.25⁴⁹. In 1981, IBM finally joined in⁵⁰ and by 1983, more than 100 software packages had been certified by Telenet as conforming to X.25(1980), including software for every major computer vendor. Another two dozen vendors supply standalone interface boxes for host-to-X.25 support. Some 57% of the hosts connected to Telenet have user-supplied X.25 interfaces⁴⁶. Finally, key users, such as the U.S. Federal Government have adopted X.25 as a standard for internal networks.

Thus X.25 is now widely available to the data communications user -- but is it used? The answer to this question is more ambiguous. Only a few of the largest private network operators have adopted X.25 internally. The public packet networks struggled for customers between 1976 and 1980. However, with many of the uncertainties surrounding X.25 resolved by 1980, traffic volume on Telenet and Tymnet began to increase rapidly with the number of sessions quadrupling in three years. Still, Telenet did not show a profit until 1983,⁴⁶ the same year in which AT&T finally began offering an X.25 based packet service of its own. On the other hand, the European PTTs, by adjusting the relative tariffs of leased lines versus packet services, are gradually forcing many users over to public data facilities. France's TRANSPAC services more than 8000 X.25 connections and carries traffic of 100 billion characters per month.⁵¹

From a technical perspective, X.25 still has both its defenders and detractors. Most of the ambiguities of X.25(1976) were resolved by X.25(1980), but in many cases the solution was to ratify multiple options or interpretations. As one particularly scathing critique by IBM put it, "The evolution of X.25 has presented somewhat of a moving target to network implementors and terminal designers alike."⁵² As a consequence, packet network services continue to differ significantly between countries (Table 7-1). This poses continuing problems for those writing X.25 host software.

The battle over datagram service, which was resolved by defining a datagram "option," ended in a clear defeat for datagram proponents. As noted earlier, no public network has offered datagram service, and revisions proposed for 1984 will eliminate datagrams from X.25 altogether. Thus, X.25 is expensive for transaction traffic and cannot be used to support packet voice.

Critics such as Pouzin continue to fault X.25 for unwarranted complexity at the packet level. Pouzin argued strenuously in 1976 for the development of a common terminal interface for both circuit and packet switched networks based on the ISO HDLC standard⁵³. The introduction of a new LAPD protocol by AT&T for its videotex service is further evidence of the need for a simpler terminal protocol.

On balance, X.25 (1976) must be seen as a technically weak standard, with X.25 (1980) as better, but by no means ideal. Revisions scheduled for adoption in 1984 should finally permit X.25 to be used by microcomputers over the dial-up network.

7.2. Lessons

X.25 represents only one of the many standards for computer communications; it is risky to attempt to read too much into a single case. Nevertheless, we believe it may be instructive for future standards setting activities to draw several lessons from this history of X.25.

Lesson 1: An Imperfect Standard is Better Than None

X.25 (1976) was hurriedly adopted with known ambiguities. Networks -- and their customers -- who implemented the 1976 version were obligated to modify their implementations to align with the 1980

Table 7-1: Comparison of Differences in X.25 Public Networks

Country	Germany	France	U.K.	Japan
Network	Datex-P	Transpac	PSS	DDX
Packet Level: Sequence Numbering	8 (Basic)	8 (Basic)	8 (Basic)	128 (Extended)
Packet Size(s) Supported (Bytes)	128	32,128	128,256, 512,1024	128,256
Maximum Window Size	7	3	7	15
When Specified	At Subscription	At Subscription	On Call Establishment or At Subscription	On Call Establishment
Reverse Charging Supported?	No	Yes	No	Yes
Link Level: Maximum Frame Size (Bytes)	128	128	256	1024
Retransmission Timeout—T1 (seconds)	3	0.4-1.5	10	2-8
Maximum number of Retransmission tries	9	10	20	25

Source:⁴⁶

version -- at significant expense. Yet X.25 has been hailed by these same networks as a great success. From their perspective, X.25 succeeded in its most important objective: it induced equipment manufacturers to take packet networks seriously and to begin designing compatible equipment. By 1975, Tymnet, RETD and Telenet had been established without an international standard interface. TCTS, the EEC, the BPO and the French PTT had committed themselves to establish networks with or without a CCITT approved standard. If these networks had been allowed to evolve independently, the chances of reaching agreement later would have been drastically reduced.

X.25 suggests that economic and competitive pressures are forcing the rapid implementation of computer communications and that these new applications will be implemented with or without standards. If standards are to make a contribution to these technologies they must be developed on a compatible time scale. The typical eight year development cycle of ISO and CCITT is far too slow in the current competitive environment. The alternative, as suggested by X.25, is to sacrifice some of the standard's rigour in favour of more rapid approval. The direct consequence is a need for subsequent changes and revision. We would argue that the imperfections of X.25 were not an aberration; rather, if, from a commercial perspective, an imperfect standard is better than none, we can expect more hurriedly developed standards in the future, and more effort expended in subsequent revisions. The alternative, to delay the benefits of new technology while standards are refined, is perceived to be too costly in a competitive marketplace.

Lesson 2: Build a coalition in private meetings with other vendors and submit a joint proposal to formal institutional standards meetings

The Rapporteur's group on packet switching failed to reach agreement whereas an informal group involving TCTS, Transpac, Telenet, BPO and NTT succeeded. This smaller group, containing those carriers committed to the implementation of packet switching, and thus with the greatest economic motivation for agreement, met more than ten times in 1975, sometimes for as much as a week, while the full Rapporteur's group was meeting only three times. The informal group then presented the full Study Group with a complete draft of a standard at the February 1976 meeting.

Our economic theory of standards suggested a positive feedback model in which the dominant economic unit eventually forces the standard. Coalition formation is one means of creating sufficient momentum. The coalition of Xerox, DEC and Intel to push for the adoption of the Ethernet local area network standard, and the moves by AT&T to solicit support by Canada and CBS for its North American Presentation Level Protocol Syntax for videotex are examples of similar coalition formation.

Lesson 3: Standards agreements for new technologies are likely to be most easily reached after there has been some practical experience with the technology, and when a number of implementations are imminent. Organizations whose implementations are imminent are the ones most motivated to develop standards.

X.25 (1976) was approved when there were only 3 networks in operation, but as many as 15 under discussion for 1980. If a standard was to benefit those 15, it had to be developed for the 1976 CCITT Plenary. The leading role in the development was taken by TCTS, Transpac and the BPO. The three networks already in operation -- RETD, Telenet, and Tymnet -- while agreeing to eventually conform, were less motivated to spearhead the development effort.

Conversely, without the experience of the three networks already in operation, plus the widely publicized ARPANET experience, it would not have been possible to generate sufficient interest in packet networks to develop a standard. The firmly rooted circuit switching tradition in the telecommunications industry had caused some reluctance during the early 1970s on the part of the PTTs and carriers to establish public packet networks. But by 1975 most had had sufficient exposure to the technology to recognize its potential. The fact that CCITT Plenary sessions are held only at four year intervals forced the proponents of a standard to move quickly in 1975 or face an additional four years delay.

The best time to develop a standard thus appears to be during a very narrow window after there is some operating experience, and when there has been a commitment by other organizations to enter the field, but before these same organizations have committed themselves to divergent approaches. The need for some operating experience before the standard is developed means that the leading

innovators may have to redesign their systems as Telenet, RETD and Tymnet have been obliged to do. (Similar redesign has been forced on Ungermann-Bass, a pioneer in local area networks, and the British Prestel videotex system -- both pioneers who got ahead of the standards making process.)

Lesson 4: Managers who can commit their organizations will be more successful in securing adoption of a standard than technical experts without decision-making responsibility

CCITT processes have traditionally been characterized by a separation of technical study groups from the more political Plenary meetings. The usual CCITT participant is only an intermediary who must check with his chiefs before agreeing to any proposal. However, the effort to develop X.25 was led by top management from the key organizations: Horton was Assistant Vice-President (Planning) of the Computer Communications Group of TCTS, Kelley was Head of the Data Systems Division in the BPO, Roberts was President of Telenet, and Picard became Directeur General of Transpac. Precisely because of the economic importance of standards to these fledgling networks, these managers took a direct interest. They had the authority to make commitments on behalf of their organizations which greatly accelerated the process.

Lesson 5: Standards agreements are more likely to be reached for "natural" interfaces, i.e., interfaces where there is a natural division in responsibility for the supply of equipment or services.

Recommendation X.25 defines the interface between customer terminal equipment and the communications network. For public data services, customer equipment is generally provided by the user rather than the network provider, thus creating a division of responsibility and a "natural" interface. For "natural" interfaces, both sides can further their self interest by adopting a standard. Network operators are freed from providing multiple interfaces to many equipment providers. To the extent that users demand data terminal equipment capable of being used on public networks, equipment providers gain a larger market if their devices can be used interchangeably in many different countries without modification.

By contrast, host-to-host standards -- e.g. the ISO's Transport Protocol -- do not define a natural division of responsibility and were not finally agreed to until 1983.

Lesson 6: The layered approach speeds the development of standards.

Recommendation X.25 separates the various network functions at the DTE/DCE interface into a physical layer, a link layer and a packet layer. In theory, layering allows standards for each layer to be developed by separate working groups, and is expected to facilitate changes to the standards as they evolve.

The history of X.25 suggests that layering does help. X.25 (1976) might not have been ready in time except that the Study Group adopted a link access procedure and a physical level standard based on the ISO HDLC proposals. In the event, ISO subsequently rejected the proposed HDLC link access procedure. A compromise procedure (LAPB) was developed jointly by ISO and the CCITT in 1977 and included in the revised version of X.25 published in 1978. No changes were required at either the physical level or the packet level. The speed with which this revision was possible was due largely to the layered structure of the standard.

The success of the layering concept is reflected in the ISO's model for Open Systems Interconnection, and in the activities of the IEEE's Local Area Network group, 802.

The cooperation with ISO leads us to our final observation, namely:

Lesson 7: Standards of higher quality and greater generality are likely to be produced if standard-setting organizations cooperate with each other during the development and drafting of new standards.

The HDLC standard was the result of considerable effort aimed at developing a more efficient bit-oriented data link control procedure for synchronous communications. Although there has often been a strong overlap in the membership of related committees, the 1977 joint session between CCITT SG VII and the ISO working party charged with developing HDLC set a precedent for formal cooperation between these two standards organizations. Efforts to institutionalize this precedent failed until, under pressure from the EEC, the ISO and the CCITT were able to harmonize their efforts to develop transport protocols in 1982.

8. Conclusion

The need to develop new computer communications standards has placed unprecedented demands on traditional standards setting processes. The development of Recommendation X.25 reflected this stress, and in the course of developing a standard, the key participants made significant changes to the process. Economic priorities were allowed to override technical concerns and a weak standard rushed to agreement. The formal, plodding procedures of the CCITT were circumvented through informal meetings among the key parties. Top managers rather than technical specialists sat in on the meetings and committed their organizations to an agreement. The principal of layering was employed for the first time, as well as an unusual degree of cooperation between CCITT and the ISO.

Current standards efforts in such areas as videotex, local area networks, or electronic message services can be expected to exhibit many of the same patterns of decision-making.

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