‘Tension between Standardisation and Flexibility’ Revisited: A Critique

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Abstract

This paper is a critique on Hanseth et al. (1996), a study that centres on the question: does standardisation fix the parameters of ICT development and thus hamper innovation. Its conclusions are based on arguments drawn from the classic OSI (Open Systems Interconnection) - TCP/IP (Transmission Control Protocol/Internet Protocol) debate.
This paper starts with an analysis of the different aspects of interoperability which OSI and TCP/IP address, and goes on to unravel the aspects which confuse the OSI-TCP/IP debate: market, technical functionality of standards, and standards procedures. I conclude that an anti-OSI stance in the OSI-TCP/IP debate clouds our view on the problem of flexibility in network evolution. The OSI and TCP/IP standards trajectories show that flexible solutions (compatible heterogeneity) have had little impact on the development of the Information Infrastructure. Is the desirability of flexibility and heterogeneous networks self-evident?

I. INTRODUCTION

The drive to research emerging standards and uncover new standardisation areas, especially in the rapidly expanding area of Information and Communication Technology (ICT), leaves little room for re-analysis and reflection. In my view, there is a need to reflect on the impact of standards on infrastructure development. In this paper I therefore forego ‘factual novelty’ and reflect on an ‘out-dated’ area of standardisation.

Internet [8] was a popular research area in the mid-1990s [e.g. 6,7,1,2]. At the time there was an urge to explain why Internet became a success. Internet standardisation was thought of as one of the factors that brought about its success. The quest for success criteria was based on hindsight. The standardisation field may stand to gain from such quests, but overall their contribution is modest. It is modest because, most likely, the researcher in question is tempted to generalise these criteria without taking the specific situation into account. A more stringent approach would be one that strives for a symmetrical explanation and offers insight into the ‘failure’ of alternative standards solutions as well. Conclusions that are based on an analysis of success are built on shaky ground - however relevant and interesting the context of analysis itself.
I refer to Hanseth *et al.* [1]. The article addresses the tension that exists between standardisation and flexibility in the light of the evolution of the Information Infrastructure (II). The authors “explore how the standardisation of II is a process that increases irreversibility and decreases interpretative flexibility of the technologies while supporting flexibility of use and openness to further changes.” (p.408). Arguments are drawn from the OSI (Open Systems Interconnection) - TCP/IP (Transmission Control Protocol/Internet Protocol) debate to illustrate their points. The body of the article consists of a presentation of the technical and institutional differences between the OSI and Internet standards (processes). The findings are interpreted from the Social Studies of Technology angle [10]. The first step of their analysis leads to a description of the irreversibility of the II system with notions of *installed base* and *network externalities*. They point to the need for flexibility in technical standards to allow further evolution of the II. In the second step of their analysis they centre on the system’s accumulated resistance to change, draw a parallel with Hughes’ concept of *technological momentum*, and criticise the latter notion because “(…) as the next version of IP in Internet illustrates, radical changes are regularly required and even anticipated.”

This paper is a critique on Hanseth *et al.* [1]. I have two main reasons for writing it. Firstly, although their conceptual approach strongly overlaps with mine, the difference between our findings is striking [2,3,4,5]. The difference implies that the outcome of scientific research is arbitrary - a conclusion which I cannot accept. Secondly, the setting of their analysis, the ‘standardisation - flexibility’ issue, is an interesting and important one. I propose to examine it further in this paper.

Because the OSI-TCP/IP debate constitutes the empirical basis for their argumentation, I start by briefly setting the scene (section II). Next, I analyse the debate (section III). I apply the Social Construction Of Technology (SCOT) approach to the interoperability problem which OSI and Internet address. This approach is a means to distinguish technical standards from institutional processes and market mechanisms. In section IV, I specify my objections to Hanseth *et al.*'s analysis of the OSI-TCP/IP debate. I round off by discussing what both analyses lead to in terms of the standardisation - flexibility issue.

II. OSI-TCP/IP DEBATE

The OSI-TCP/IP debate started approximately in 1991. OSI and Internet's TCP/IP are two architectural frameworks. Both are comparable in that they model system interconnection with layers. Each layer contains one or more protocols. The architectural frameworks, the accompanying standards and the standard-conform products and services are henceforth referred to as *standards trajectories.*

The rise of Internet and the growing use of TCP/IP-based services were accompanied by increasing criticism on the OSI-standards trajectory. Fierce discussions flamed up about the advantages and disadvantages of both standards trajectories. Drake characterised it as a religious war [7]. In Table 1 some of the arguments are called to mind. The overview sums up the essence of the debate at the close of 1994, and is discussed more extensively in the next section.

III. ANALYSIS OF PROBLEMS AND SOLUTIONS

The OSI and Internet standards trajectories are to a certain degree comparable, but they differ in important respects. In this section I analyse their similarities and differences by examining the problems they address and the solutions they stand for. Central to both architectural frameworks is that they were designed to answer to the problem of interoperability. This will be my point of departure. The conceptual framework used is based on the SCOT approach.

A. SCOT Approach

The SCOT approach emphasises the principle multi-directionality of technology development [11]. The reasoning is as follows. People attach different meanings to artefacts. They therefore use artefacts differently. For example, the computer is a text processing machine to some people, a means of playing games to others, etc. Each use may trigger specific technological trajectories (soft- and hardware development). Thus, each meaning embeds a potential direction in which an artefact may develop. In principle, the evolution of an artefact can follow several development trajectories (*multi-directionality*). Analyses of technology development should be able explain why artefacts develop in certain directions and not in others (i.e. *symmetrical explanation* [12]).

The SCOT approach further argues that different meanings or problem definitions attest to the *interpretative flexibility* that exists in respect to artefacts [13]. Social groups negotiate about these meanings and problem definitions. In the process of acquiring consensus, the interpretative flexibility is reduced. This is called *closure*. Closure leads to *stabilisation* of the meaning of the artefact. Since not all parties need agree on this meaning, there are different degrees to which members of a group feel committed to a meaning or a problem definition (i.e. *degrees of inclusion*).

Table 1: Main points of criticism made in the OSI - TCP/IP debate [14].

OSI-protocols	TCP/IP-protocols
too complex & too dear to implement	simple, lacks richness, cheap
large long term profit, does not answer to problems of companies	answers to direct needs
developed in open standards forum	developed in secluded environment
too few OSI-products, only used in pilot systems	rapid and broad availability of products
standards are not free of charge	free and easily accessible standards
too lengthy standards process	rapid standards process
lack of interoperability	implemented before approved as standard; problems with interoperability outside of UNIX environment

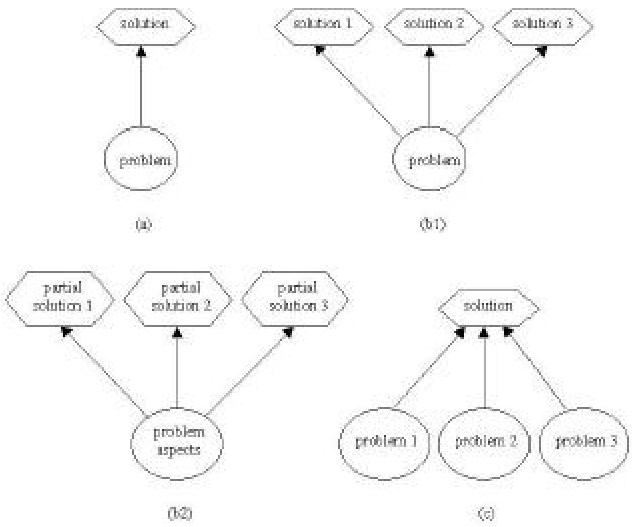


Figure 1: Problem-solution relations [5].

Expanding on the SCOT approach, if one examines an artefact and retraces its development path, the evolving artefact represents a series of solutions to select problems. There are several problem-solution relations (Figure 1). In some situations, groups working in the same field will interpret the problem differently and solve it by their own means (diverse problems, diverse solutions and thus diverse artefacts). In retrospect, different artefacts may seem to be a solution to the same problem. For example, electronic communication and physical transportation both address the problem of contacting someone. The solutions represent alternatives (substitute solutions, (b1)). Solutions may also address different aspects of a problem (supplementary solutions (b2)). Or, one artefact may solve different problems (c). In other situations, it is important that various groups agree on the problem definition and define one common solution (a).

Below, I use the SCOT notation technique in a way comparable to flow-charts for decision-making. Instead of 'following the actors', as is usual in the SCOT approach, I ‘follow the issues', that is, the chain of problems and solutions. I first analyse the architectural frameworks of TCP/IP and OSI. Of interest is whether the problems were identical and to which problem(s) the architectures offered a solution.

B. Meaning of Initial Architectures: The Problem of Interoperability

Interoperability of products and services is a central problem in the field of ICT standardisation. In the 1970's several computer industries developed proprietary standards architectures in answer to interoperability problems *within* their own system (intra-system interoperability, see Figure 2). The same problem arose *between* these proprietary systems (inter-system interoperability). Notably, two groups addressed the lack of inter-system interoperability: the ARPA project (Advanced Research Projects Agency) and the formal standards committees of the ISO (International Organization for Standardization) and the CCITT (Comité Consultatif International Télégraphique et Téléphonique of the International Telecommunication Union (ITU)). See Figure 3. The ARPA project was an internetworking project for communication across heterogeneous packet networks, co-ordinated by DARPA (Defense Advanced Research Projects Agency) and funded by the US government (Department of Defense). Working solutions were sought. DARPA was interested in a *functioning system*. The effort ultimately led to the TCP/IP architecture.

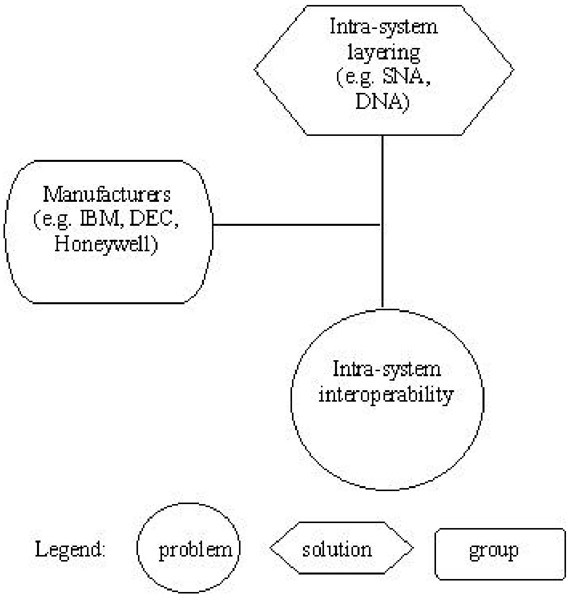


Figure 2: Proprietary solutions to intra-system interoperability.

An ISO committee, later joined by a CCITT Study Group, developed the OSI reference framework. OSI mainly served two purposes. First, it should offer a *future-proof framework* with which complex standardisation areas could be broken down into manageable work items. Subdivision would allow standardisation of independent but interrelated protocols to take place in parallel. Second, its purpose was to provide *non-proprietary solutions* for system interoperability, an aim comparable to that of the ARPA project, but broader in scope. Figure 3 emphasises the common problem definition that underlies ARPA and OSI efforts (interoperability), the two main groups involved and the different solutions sought. The arrow indicates that the TCP/IP architecture is a derivative solution to the problem of interoperability.

Thus, although the problems which OSI and TCP/IP addressed were the same - i.e. interoperability - the aims of DARPA and ISO/CCITT differed, as did the scope of the architectures that resulted. TCP/IP was a by-product of a functioning system, abstracted from a working prototype for internetworking [15]. It was derived *ex post.* OSI, on the other hand, aimed at principled internetworking solutions and provided an *ex ante* reference framework to guide standards activities. The resulting standards should become the building blocks for functioning systems in various networking environments. In other words, the OSI and TCP/IP architectures were different solutions to aspects of the same problem (Figure 1, b2) and were merely substitutes in the vaguest sense. They were foremost supplementary solutions to the problem of interoperability.

Furthermore, the difference in the way they were produced is significant. Computer research scientists designed and implemented TCP/IP versions, which were tested with the help of different contractors [16]. Since OSI was a framework for developing standards, no testing of implementations was involved. TCP/IP developed in a protected niche, with a circumscribed goal, financial, material and expert resources, whereas OSI developed within the more diffuse environment of formal standardisation. Clearly, the former situation provides the better means to control, manage and co-ordinate architectural developments and outcomes - as is the case with proprietary architectural developments.

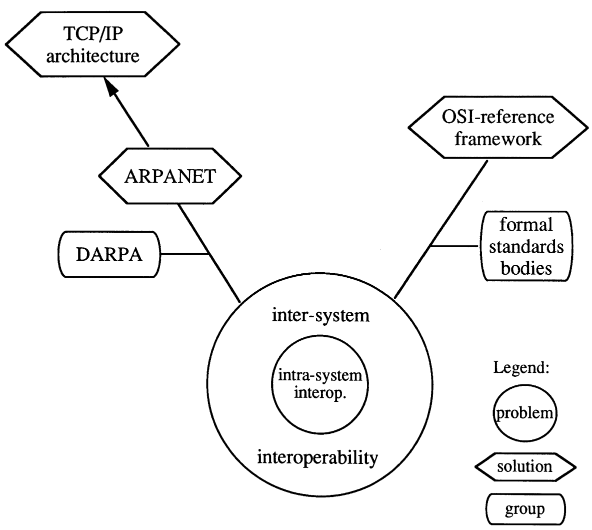


Figure 3: Architectural solutions to the problem of intra-system and inter-system interoperability.

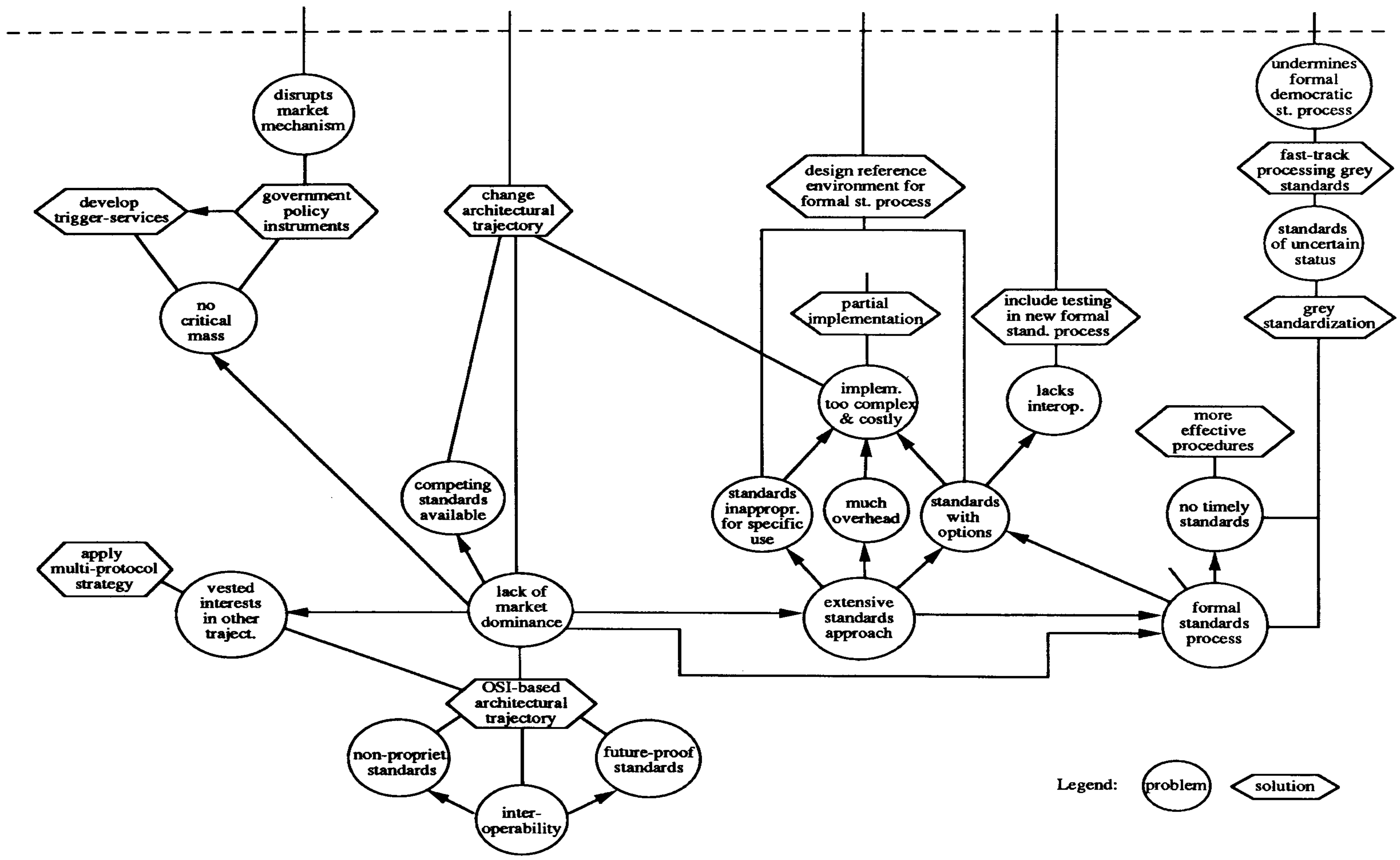
C. Criticism on the OSI Trajectory

By the mid-1980s there was strong support for OSI. The ISO and the CCITT had formally agreed to work within the OSI framework. Most national and regional standards bodies backed up OSI standardisation. Further support came from industrial user groups (OSI-based Manufacturing Automation Protocol/ Technical and Office Protocol, MAP/TOP), regional groups of computer manufacturers (the European Standards Promotion & Application Group (SPAG), the Corporation for Open Systems in the US, the Promoting Conference for OSI in Japan), and mixed regional and international groups (OSI workshops). An OSI-oriented network of actors developed. Within Europe, for example, the SPAG initiated co-operation with the European MAP User Group, the European TOP users and the European Computer Manufacturers Association. To develop European-wide functional OSI standards, manufacturers, users, service providers and academics set up a regional OSI workshop (European Workshop for Open Systems, EWOS). The European government encouraged these developments for it saw in OSI a means to boost its IT industry. It created incentives for OSI-conform product demand and a favourable regulatory environment by exemplifying OSI in its directives and resolutions and demanding OSI-compliance in Community projects. In the late 1980's the US federal government, too, adopted OSI. Wide interest heightened the stakes in OSI standards processes.

But despite support, OSI-based products did not acquire market dominance. In retrospect, several factors can be said to have hampered expansion of the OSI market (see Figure 4). Firstly, there is the installed base of customers and the vested interests of suppliers in proprietary architectures. Vested interests discouraged a change of trajectory.

Secondly, the problem could be said to be one of marketing. Developers need to ‘sell’ their standards to potential implementers and users. A critical mass of providers and procurers is required before a self-propelling mechanism of diffusion takes over. Despite the favourable regulatory conditions for creating an initial critical demand, wider diffusion did not occur.

Figure 4 (next page): A selection of problems and solutions in the OSI trajectory. Plain lines indicate a problem-solution relation. Arrows indicate partial problems and derivative solutions. The figure is to be read from the bottom upwards.


disrupts market mechanism
government policy instruments
develop trigger-services
no critical mass
change architectural trajectory
competing standards available
lack of market dominance
vested interests in other traject.
apply multi-protocol strategy
OSI-based architectural trajectory
non-propriet standards
future-proof standards
inter-operability
design reference environment for formal st. process
partial implementation
implem. too complex & costly
standards inappropr. for specific use
much overhead
standards with options
extensive standards approach
include testing in new formal stand. process
lacks interop.
undermines formal democratic st. process
fast-track processing grey standards
standards of uncertain status
grey standardization
more effective procedures
no timely standards
formal standards process
Legend:
problem
solution

Thirdly, OSI standardisation may have been too comprehensive. OSI's objective of implementation- and field-independent standards was ambitious. Such standards come at a cost. According to some critics, the costs of implementation were too high. In their opinion OSI standards represented: high overheads, too many options and complex answers to specific and simple needs. Standard options, in turn, bring along interoperability problems. All-embracing standards not only complicate implementation, but are also expensive. In consequence, implementers who succumb to external pressure for OSI-compatibility may choose partial implementation of a standard. And, indeed, to cut down costs, some OSI implementers left out functionality's that were intended to be part of the standard-conform product.[30] Nominally OSI-compatible products result. Such implementations damage the reputation of OSI products.

Fourthly, some criticisers have highlighted the lack of workability of OSI standards. Experience with the implementation of standards often led to revisions. Defect reports followed the approval of OSI standards. This problem could be regarded as typical for the formal standards bodies, who strive for implementation-independent standards. In this respect, a change in the formal process could have been pursued. Incorporating testing procedures would have been a means to address incompatibility between different implementations of OSI standards. A more radical solution would have been to design a reference environment, which would better focus the comprehensive OSI approach (that is, address a more limited set of functions).

Fifthly, if the central problem is seen to be the lack of timely availability of OSI standards, acceleration of formal procedures could be a solution. Then again, there may be recourse to alternative standards fora (e.g. IEEE or Internet).

In other words, depending on the way the 'OSI problem' is defined, its solution will be sought in new market-oriented mechanisms, in changes in the standards process or in revised standards and architectural objectives. This threefold distinction in standards, standards setting and market setting also turns up in the evaluation of Internet. Roughly speaking, Internet is presently valued for three reasons: for the usability of the TCP/IP architecture and the Internet standards (functionality), for the way TCP/IP-based services have conquered the market and, thirdly, for its standards procedures. These facets are elaborated below.

D. Market of TCP/IP-Based Services

Initially, the US government and scientific circles supported TCP/IP. Federal researchers were encouraged to connect to ARPANET, the predecessor of Internet, from the early 1980's onward [16, p.16]. Notably, the efforts of the National Science Foundation (NSF) expanded the user base in an incremental manner. The NSF sponsored connections to Internet, funded new sites, financed links to its supercomputer centres, supported the improvement of Internet-routing technology and stimulated the distribution of network software. The US government started out by prescribing TCP/IP as one of its Defence standards. It later made TCP/IP mandatory for ARPANET. The federal agencies that used TCP/IP-based services founded the Federal Research Internet Coordinating Committee (FRICC). FRICC financed Internet research activities and its organisation [17]. The close involvement of US government and scientists provided a stable initial user base for Internet. Wide and free availability of TCP/IP supporting software in UNIX systems and LANs eased further growth of the TCP/IP-based market.

In the late 1980's there was a drawback. The signs favoured the OSI trajectory, which was gaining proponents world-wide. In order to prevent isolation, the US federal government switched from TCP/IP to OSI.

The rising popularity of Internet's TCP/IP-based services has its roots in the early 1990s. Between 1990 and 1992 the number of Internet hosts installed world-wide showed an exponential growth (estimated from 130,000 to 700,000 hosts [18]). Academics outside the US started using Internet. This group was followed in 1993 by commercial Internet users [19]. Prominent reasons for its popularity were that the use of Internet services was easy, and most of the information and software were provided free of charge.

E. Functionality of Standards

Exceptions aside, TCP/IP and OSI protocols support similar communication functions (e.g. email and file transfer). In the debate they are staged as competitors. A widely shared view is that OSI standards are too complex and too expensive to implement, while TCP/IP standards are simple and applicable [20]. But the arguments pro and contra are not systematically conclusive. They appear not to apply, for example, to the network management-protocols: Simple Network Management Protocol (SNMP) of Internet and the Common Management Information Protocol (CMIP) of ISO/IEC (International Electrotechnical Commission). The former was a simple, datagram-based solution, which was soon to be implemented, whereas CMIP was too complex [20]. It was too expensive to implement and its development took too long. However, others hold that CMIP itself is a relatively simple standard [21]. CMIP's complexity and the costs involved in CMIP-implementation, mentioned by Scales, do not concern CMIP but the OSI building blocks CMIP uses. Perhaps more important, the strengths of the two network management protocols lie in different areas. Internet's protocol is well equipped for straightforward management tasks and to operate equipment with a limited memory capacity. It is especially suitable for smaller networks. In larger, complex networks OSI's CMIP is both more efficient and more flexible [21].

More in general, the two protocol families seem to address different user settings. It is, therefore, a simplification to conclude that the success of Internet services reflects the quality or technical superiority of underlying standards.[22]

F. Comparison of Standards Processes

There are important similarities between Internet and formal standardisation. In both environments volunteers do the work. Decisions are taken in consensus. Both adhere to an open and democratic process. The fora have similar provisions to cope with intellectual property rights. And, in both environments the application of standards is voluntary. There are, however, also some relevant differences. For example, it is undeniable that the bottom-up standards approach of Internet is less time-consuming than OSI's top-down approach. The reasons are manifold. They do not permit simple judgement and are discussed below.

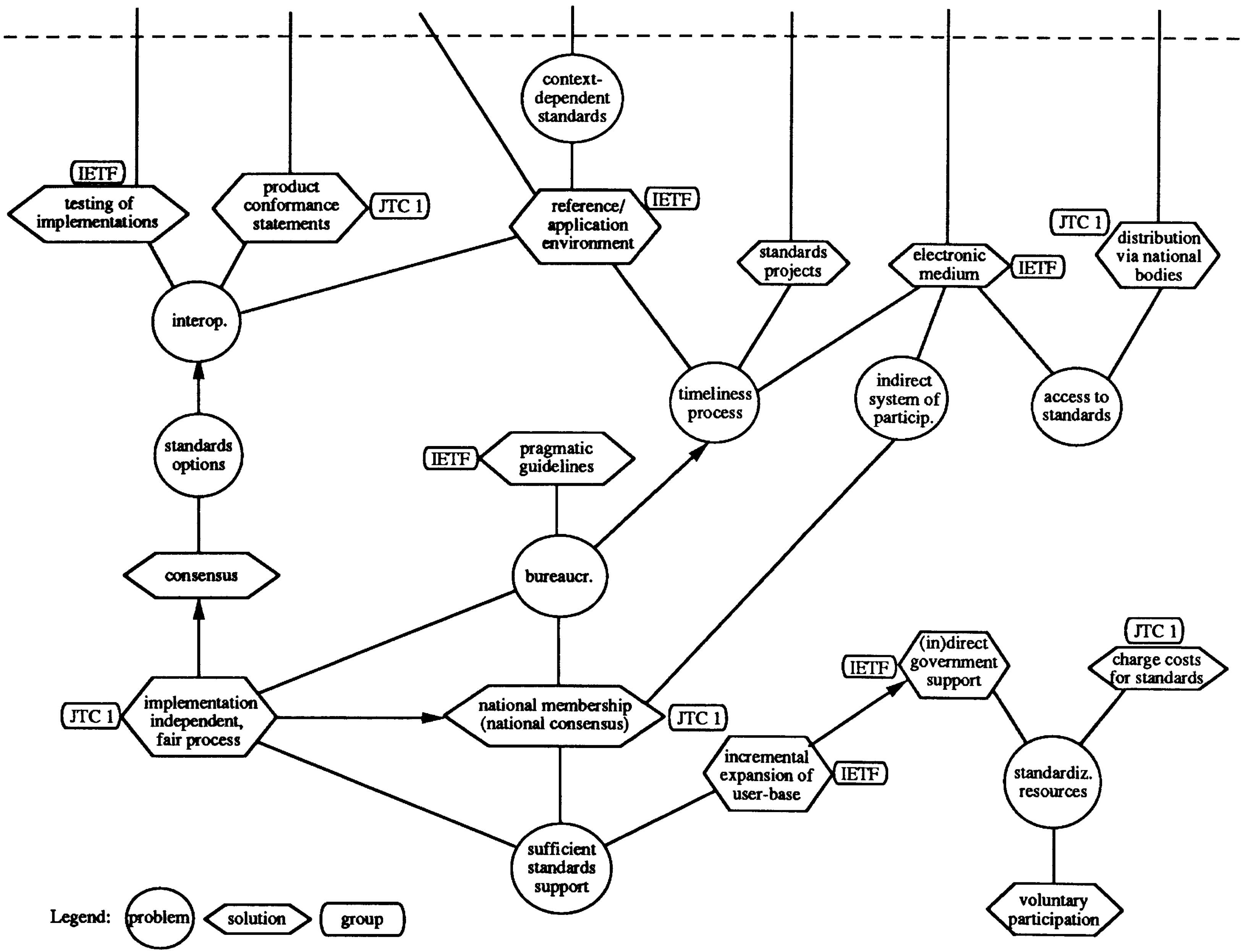
The development of OSI standards has since 1987 been addressed by the ISO/IEC's Joint Technical Committee 1 (JTC 1). The TCP/IP protocol family is developed in the Internet Engineering Task Force (IETF). In a study that compares the effectiveness and efficiency of their standards processes, several differences are noted [2]:

- IETF standardisation has no formal membership. There is no system of representation. Anyone can participate *a titre personnel*. This differs from JTC 1. Its members are the national standards bodies, which represent the national interest. Although informally participation is open to all, for the voting on drafts national standpoints are required. The extra national layer in JTC 1 makes its standards process less transparent and less effective.
- IETF's primary medium for discussion is the electronic mailing list. JTC 1 standardisation predominantly takes place in face-to-face sessions. One may assume that the electronic medium - if available - is an accessible medium, which eases contributing, and commenting. If so, use of the medium could raise the quality and applicability of ultimate standards proposals.
- IETF distributes standards free of charge. They are rapidly available and accessible. JTC 1 sells paper copies. Free use and the electronic, immediate availability of Internet-standards heightens the likelihood of applying these standards.
- JTC 1 supports the development of Product Conformance Statements. Although such statements do not guarantee that implementations will interwork, they reduce risks. Additional statements about the interoperability of implementations would be desirable. Although Internet has limited but seemingly adequate ways to test interoperability of implementations, it lacks the necessary procedures to assess standards conformance. Conformance Statements would be desirable as Internet-standards regularly suffer from ambiguity.

IETF procedures leave room for alternative action [23]. According to the formal IETF documents, in situations of conflict the development of alternative standards proposals is encouraged. The efficacy of the respective implementations will determine which standard will survive. Internet is, in short, a less bureaucratic environment of standardisation than ISO/IEC JTC 1. The more bureaucratic methods of ISO/IEC ensue among other things from the ideological feature of impartiality [3]. It implies, apart from interest independent procedures, also implementation independence and financial independence. Any impression of preferential treatment should be avoided. Therefore, as the IEC formulates it, "(...) any direct funding from governments to the IEC centrally should [also] be avoided." [24]

Internet matured through US government support. The core Internet protocols was developed in a project environment. Much of the efficiency in IETF standardisation can be attributed to the project features, which characterised the development of the Internet infrastructure. It initially drew a select group of standardisers. Reference implementations were freely available. New requirements and technologies were assimilated step-by-step. Workable solutions were sought and tested on site. The application environment of Internet narrowed down the potential number of solutions. This practical focus strongly eased standards development and the effectiveness of the process. The initial project environment of Internet's standards process complicates a comparison with the ISO/IEC's process, which from the start was compelled to find implementation independent solutions for the international community. In addition, the ISO/IEC procedures needed to serve a broader domain than the Internet Society.

Figure 5 (next page): A selection of problems experienced in the standards processes of the JTC 1 and the IETF and their potential solutions. (Arrows indicate that partial problems and partial solutions are concerned. Rounded boxes specify which organisation is associated with the problem or solution. The figure should further be read as the previous.)


IETF
testing of implementations
product conformance statements
JTC 1
context-dependent standards
reference/ application environment
IETF
standards projects
electronic medium
IETF
JTC 1
distribution via national bodies
interop.
timeliness process
indirect system of particip.
access to standards
standards options
IETF
pragmatic guidelines
consensus
bureaucr.
(in)direct government support
IETF
JTC 1
charge costs for standards
JTC 1
implementation independent, fair process
national membership (national consensus)
JTC 1
incremental expansion of user-base
IETF
standardiz. resources
sufficient standards support
voluntary participation
Legend:
problem
solution
group

A last difference mentioned here concerns their respective approach to participation. The 'democratic ideology' of formal standards bodies emphasises the diversity of interest groups and their requirements. Explicitly, they aim to take account of the interests of less influential groups. In the IETF, 'openness' is equivalent to lack of formal obstruction to participation, which again eases progress in standardisation.

Thus, because of their different points of departure it is precarious to carry the comparison between ISO/IEC JTC 1 and Internet standardisation too far. This applies in particular to process accelerating factors in IETF standardisation such as financial support, pragmatic guidelines for participation and the focused search for solutions in an application environment.

Figure 5 interprets and interrelates a select number of problems and solutions in the standards processes of the JTC 1 and the IETF. Because JTC 1's solutions answer to a more complex standards environment, they are less appropriate to solve IETF problems. Therefore the figure is favourably biased towards IETF standards process. For example, timeliness is a problem in various standards fora. The problem can be solved in different ways. The IETF does so by using electronic mailing lists to draw up standards. Some JTC 1 committees are starting to do likewise. A second means of accelerating the process is to restrict the scope of standardisation to a reference environment. This could be developed into a test-site, which would also solve the problem of interoperability. And so forth.

In 1994 the sting was removed from the OSI-TCP/IP debate. Governments relinquished their 'OSI only' stance. JTC 1 and the Internet Society formalised co-operation [26]. Coexistence and interworking efforts between the two standards trajectories expanded [27]. By the mid-1990s, advocates of the two trajectories participated in each other's standards activities. Increasingly standards of different architectures were used in combination. A multiprotocol-practice was developing in which, for example, proprietary standards (e.g. IBM, Novell, and DEC) were used in combination with OSI and Internet standards

IV. DIVERGENT FINDINGS

In the OSI-TCP/IP debate, issues that concern the market, technical functionality, and standardisation procedures have often been oversimplified and confused. As a consequence, the lessons that can be drawn from the OSI trajectory still merit attention. The OSI trajectory is of particular interest in respect to the issue of ‘flexibility in standardisation’, which Hanseth *et al.* [1] address. As was argued in the previous section, the OSI approach was specifically designed to solve the problem of inter-system interoperability in a system independent and flexible manner. The expectation was that a flexible and comprehensive framework for standardisation (i.e. technical flexibility) would easily win over implementers and potential users. This did not occur. Hanseth *et al.* provide several explanations. But, in my view, they confuse the issues and therefore weaken their basis for conclusions about the relation between flexibility, standardisation and infrastructure development. I specify my objections below, starting with two factual points where my findings [3,4] differ from theirs, and proceed with the two most salient differences in interpretation.

- Hanseth *et al.* (p.413) claim that OSI standardisers did not consider compatibility with non-OSI protocols. I would argue the opposite. Indeed, the degree to which OSI standardisers attempted to incorporate protocols from other sources very much complicated the standards process. An example is the Transport Protocol (TP). In order to accommodate the interests of different parties, five protocol classes were agreed upon (TP0-TP4). One of these, TP4, was a negotiated by the United States, who sought compatibility with ARPA’s TCP. Because of it, OSI applications could run on Internet protocols and vice versa. Moreover, a multiprotocol-practice developed (see section IIIF). It is, therefore, incorrect to state that “the protocols cannot run alongside other networks, only within closed OSI environments” (p.413).

- Hanseth *et al.* (p.414) imply that the message handling solution of the OSI trajectory, developed in 1988, was not downward compatible with the 1984 version. This is inaccurate. Two separate standards bodies, the ISO and the CCITT co-operated on the 1988 version. They were faced with the dilemma of burdening newcomers with the added features required for downward compatibility, and starting afresh with a leaner standard. The members of the CCITT, Public Telephone Operators, insisted on downward compatibility because they had implemented the 1984 version and were still operating it in 1988. The CCITT members got their way.

- “(…) The OSI protocols are not related closely enough to the already installed base of communication systems. The installed base is irreversible because the kind of radical, abrupt change implicitly assumed by the OSI developers is highly unlikely.” (p.419) The context of this quotation is a discussion on the lack of diffusion of OSI products. This is an undeniable fact in the period 1992-1996. Especially if one compares the market of

OSI products to the exponential growth Internet use. But in the period prior to 1992, to which the authors refer, 'the installed base' primarily consisted of proprietary systems. OSI - rather than Internet - standardisers tried to ensure compatibility with these systems. If we compare the two trajectories, initially both did not have an 'installed base'. The (lack of) free distribution of software is a more symmetrical explanation for why Internet took off (TCP/IP software via UNIX [2]) and OSI did not, despite the strong support for OSI in the late 1980s. [28]

- Hanseth *et al.* treat the Internet standards setting on a par with OSI's. Both are referred to as 'formal standards bodies' (p.411). As I described previously, OSI developed in the relatively open standards environment of the ISO and the CCITT, and later ISO/IEC JTC 1 and ITU-T (standardisation sector of the ITU). Internet started off in the closed, regulated setting of the US government. (E.g. the use of TCP/IP for ARPANET became mandatory in 1983 [16].) Standards work was carried out by a DARPA committee (the IAB) from 1983 to 1989. From 1989 onwards the IETF took over. The IETF has grown into a full-fledged standards environment. But even if Hanseth *et al.* restrict their comment to the IETF period, the differences between the IETF and ISO/IEC JTC1 are still manifold (see section IIIF). By categorising both as formal settings of standardisation, the influence of differences in institutional background on the respective standards trajectories are by-passed, which does not seem to agree with the authors' specific interest in institutional mechanisms (p.408, p.420).

The early Internet standards trajectory cannot be exemplified as the route to follow in order to achieve functionally flexible standards. Neither is the OSI trajectory a suitable negative example in this respect.
If we try to relate the degree of technical flexibility incorporated in standards to technical infrastructure development, OSI's comprehensive (flexible) standards foremost supported the development of a heterogeneous infrastructure. Conversely, Internet standards have primarily led to expansion of a homogeneous (Internet-) infrastructure. In the OSI-TCP/IP debate, the size of the Internet market and the accessibility of the Internet infrastructure are emphasised. And, indeed, in market terms OSI's flexible standards have had much less influence on the development of the Information Infrastructure than Internet's working solutions. The question is, therefore, to what end do we need flexible standards?

V. DISCUSSION: STANDARDISATION AND FLEXIBILITY REVISITED

In Hanseth *et al.* arguments from the OSI-TCP/IP debate are used to illustrate the relation between standardisation, flexibility and the development of the Information Infrastructure. I have analysed this debate and have come to different conclusions. I conclude that, the OSI and TCP/IP architectures address different aspects of the problem of interoperability and represent supplementary solutions. This complicates the comparison. Furthermore, too little distinction is made in the debate - and by Hanseth *et al.* - between criticism and praise related to market-share, technical functionality of standards and standardisation procedures. One of the consequences is, that those who exemplify Internet standardisation without disentangling these elements are, in my view, making a anachronistic plea for building networks in protected niches and under regulatory conditions. For, Internet standards started off as a 'company' initiative, and subsequently developed from *de jure* standards (US government regulation) to *de facto* standards.
In respect to the 'standardisation - flexibility' issue, Hanseth *et al.* exemplify the flexibility of Internet standards as opposed to OSI standards. However, from the start OSI standards were designed to be flexible par excellence. I refer here to flexibility in the sense of *compatible heterogeneity* [29]. The OSI standards trajectory supported the development of a heterogeneous technical infrastructure (e.g. usable in different application and system environments). Internet standardisation, on the other hand, primarily elaborated and extended its own, working infrastructure. It did so successfully. If we compare the impact of both standards trajectories on the development of the Information Infrastructure, in retrospect, the latter clearly had a stronger market impact. This indicates that technically flexible standards and heterogeneous networks were not predominant conditions in the previous stage of network growth (i.e. the diffusion of network uses and the development of new services).
All standards trajectories, proprietary trajectories and Internet included, pay attention to compatible heterogeneity - as is evidenced by current multiprotocol practices. But the degree to which this occurs is modest. Technically, a homogeneous network, based on one protocol family, is easier to run and more reliable. From the perspective of the user, as long as networking remains transparent, the user will be satisfied. Maybe the average user is not worse off with proprietary and *de facto* network solutions. We must ask ourselves, whether desirability of network flexibility and heterogeneity is as evident as it may seem. Their absence is mainly a problem for specific application areas. Should these areas fend for themselves, or is there an additional public benefit in co-ordinating compatibility efforts?

VI. REFERENCES

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[8] The term 'Internet' refers in this paper to (a) the TCP/IP-family of protocols (the core of which consists of the Internet Protocol, the Internet Control Message Protocol, the Transmission Control Protocol, the User Datagram Protocol and the File Transfer Protocol [9]) (Transmission Control Protocol/Internet Protocol); (b) to a group of TCP/IP-based services, and (c) to "(...) a loosely organised international collaboration of autonomous, interconnected networks; it supports host-tot-host communication through voluntary adherence to open protocols and procedures defined by Internet Standards." (RFC 1603, *IETF Working Group, Guidelines and Procedures,* E. Huizer & D. Crocker, March 1994, p.2).

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[10] The central concepts they use are *interpretative flexibility*, *closure* and *stabilisation* (Social Construction Of Technology approach; e.g. Pinch & Bijker), *technological momentum* (system theory; e.g. Hughes), and *alignment through standards* and *irreversibility of translations of the actor network* (actor network theory; e.g. Callon). See e.g. the following three contributions in W.E. Bijker, Th.P. Hughes & T.J. Pinch (Eds.), *The Social Construction of Technological Systems. New Directions in the Sociology and History of Technology*. Cambridge, Massachusetts: MIT Press: Pinch, T.J. & W.E. Bijker. 'The social construction of facts and artefacts: or how the sociology of science and the sociology of technology might benefit each other', pp.17-50; Hughes, T.P.. 'The evolution of large technological systems', pp.51-82; Callon, M.. 'Society in the making: The study of technology as a tool for sociological analysis', pp.83-103.

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[28] The authors do not explain on what grounds they attribute the - unrealistic - expectation of ‘abrupt change’ to OSI developers (- nor its causal relation with the irreversibility of an installed base).

[29] I use the term to refer to interconnections between, what David & Bunn call, complementary and substitute systems (David, P.A. & J.A. Bunn (1988). The Economics of Gateway Technologies and Network Evolution: Lessons from Electricity Supply History. *Information Economics and Policy, 3*, pp.165-202.)

[30] For example, there are implementations of File Transfer, Access & Management (FTAM-OSI) which make it impossible to update the same file from different locations, although this functionality is incorporated in the standard. Such unintended OSI implementations are cheaper, but they entail a loss of functionality. (private communication, Eddie Michiels)