DEFINING DIGITAL PRESERVATION WORK: A CASE STUDY OF THE DEVELOPMENT OF THE REFERENCE MODEL FOR AN OPEN ARCHIVAL INFORMATION SYSTEM

by

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To Al Lee (1942-2004)

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I've long felt that the acknowledgements sections of most academic texts are written completely backwards. They begin by recognizing the set of individuals who provided some form of explicit intellectual contributions to the project and end with a cursory nod to the individuals whose lives are intimately connected to the work of the author. Family, friends and others who are most responsible for the success of a study find their place somewhere after those who provided clerical support and money to attend conferences. With the risk of shocking the academic sensibilities of the reader, I've chosen to take a different approach.

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Like the Reference Model that is the focus of this study, my dissertation is an artifact that resides within a complex network of actors and resources. I may be the individual who has claimed authorship for the document, but it is certainly not a product of me alone. Nor can I claim the right to determine the ultimate meaning and importance of the work. That is a responsibility shared by the many individuals I have identified in these acknowledgements and many I have not. It has been a privilege to play my part in the process.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ACRONYMS

ACM	Association for Computing Machinery
ADS	Astrophysics Data System
AES	Audio Engineering Society
AFNOR	Association Française de Normalisation
AHDS	Arts and Humanities Data Service
AIC	Archival Information Collection
AIIM	Association for Information and Image Management
AIP	Archival Information Package
AIU	Archival Information Unit
ANSI	American National Standards Institute
ANT	actor-network theory
APPM	Archives, Personal Papers and Manuscripts
APL	Applied Physics Laboratory
ARC	Ames Research Center
ARPA	U.S. Advanced Research Projects Agency
ASEE	American Society for Engineering Education
ASCII	American Standard Code for Information Interchange
AWIICS	Archival Workshop on Ingest, Identification and Certification Standards
BMDO	Ballistic Missile Defense Organization
BnF	Bibliothèque nationale de France (National Library of France)
BNSC	British National Space Centre
BSI	British Standards Institution
CCLRC	Council for the Central Laboratory of the Research Councils
CCSDS	Consultative Committee for Space Data Systems
CDF	Common Data Format
CDO	Content Data Object
CDPP	Centre de Données pour la Physique des Plasmas Naturels (Data Center for Natural Plasma Physics)
CD-ROM	Compact Disk – Read-Only Memory
CEDARS	CURL Exemplars in Digital Archives
CENDI	Commerce, Energy, NASA, NLM, Defense and Interior
CENL	Conference of European National Libraries
CEOS	Committee on Earth Observation Satellites
CER	Center for Electronic Records

CESSDA	Council of European Social Science Data Archives
CIP	Catalogue Interoperability Protocol
CLIR	Council on Library and Information Resources
CNES	Centre National d'Etudes Spatiales (French Space Agency)
CNI	Coalition for Networked Information
CNRI	Corporation for National Research Initiatives
CODATA	Committee on Data for Science and Technology
CODMAC	Committee on Data Management, Archiving and Computation
COTS	commercial off-the-shelf
CPA	Commission on Preservation and Access
CRC	Cyclical Redundancy Check
CRL	Center for Research Libraries
CSC	Computer Sciences Corporation
CSOC	Consolidated Space Operations Contract
CS-TR	Computer Science Technical Reports
CURL	Consortium of Research Libraries in the British Isles
DAAC	Distributed Active Archive Center
DADs	Digital Archive Directions Workshop
DBMS	Data Base Management System
DCC	Digital Curation Centre
DCP	Digital Collection Profile
DDI	Data Documentation Initiative
DDL	Data Description Language
DDS	Discipline Data System
DED	Data Entity Dictionary
DERA	UK Defence Evaluation and Research Agency
DFG	Deutsche Forschungsgemeinschaft (German Research Foundation)
DI	descriptive item
DIP	Dissemination Information Package
DIS	Draft International Standard
DLF	Digital Library Federation
DMI	Data Management Initiative
DOD	U.S. Department of Defense
DOI	Digital Object Identifier
DPC	Digital Preservation Coalition
DSEP	Deposit System for Electronic Publications
DTD	Document Type Definition
DVD	Digital Video Disk
EAD	Encoded Archival Description
EBCDIC	Extended Binary Coded Decimal Interchange Code
ECMA	European Computer Manufacturers Association
ECS EOSDIS	EOSDIS Core System
EDF	Electricité de France
eLib	Electronic Libraries Programme
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System

ER	entity-relationship
ERA	Electronic Records Archives
ESA	European Space Agency
ESOC	European Space Operations Centre
EU	European Union
FDIS	Final Draft International Standard
FFRDC	federally funded research and development center
FGDC	U.S. Federal Geographic Data Committee
FITS	Flexible Image Transfer System
FLICC	Federal Library and Information Center Committee
FSMS	File Storage Management Systems
FTP	File Transfer Protocol
GAO	U.S. General Accounting Office (since 2004, Government Accountability Office)
GIF	Graphics Interchange Format
GIS	Geographic information system
GM	General Motors
GOSIP	Government Open Systems Interconnection Profile
GPO	U.S. Government Printing Office
GSA	U.S. General Services Administration
GSFC	Goddard Space Flight Center
GSOC	German Space Operations Center
HDF	Hierarchical Data Format
HFMS	Hierarchical File Management System
HPCC	High Performance Computing and Communications
IASSIST	International Association of Social Science Information Service and Technology
IBM	International Business Machines
ICA	International Council on Archives
ICS	Interoperable Catalogue System; or International Classification for Standards
ICSTI	International Council for Scientific and Technical Information
ICSU	International Council for Science
ICT	information and communication technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IFDO	International Federation of Data Organisations
IGY	International Geophysical Year
IITA	Information Infrastructure Technology and Applications
IMS	Information Management System
IO	Information Object
IP	Internet Protocol
IPMS	Institution of Professionals, Managers and Specialists
IS	information systems
ISBN	International Standard Book Number

ISO	International Organization for Standardization
ISSC	International Social Science Council
IUE	International Ultraviolet Explorer
JASIST	Journal of the American Society for Information Science and Technology
JCDL	Joint Conference on Digital Libraries
JISC	Joint Information Systems Committee
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
JSTOR	Journal Storage
JTC 1	ISO/IEC Joint Technical Committee 1
JVM	Java Virtual Machine
KB	Koninklijke Bibliotheek (National Library of the Netherlands)
KSC	Kennedy Space Center
LASP	Laboratory for Atmospheric and Space Physics
LC	Library of Congress
LSDA	Life Sciences Data Archive
MARC-AMC	MAchine Readable Cataloging, Archives and Manuscript Collections
MER	Managing Electronic Records (Cohasset Associates Conference)
MIS	management of information systems
MSFC	Marshall Space Flight Center
MSS	mass storage systems
MSST	Mass Storage Systems and Technologies
NAGARA	National Association of Government Archivists and Record Administrators
NAL	U.S. National Agricultural Library
NARA	U.S. National Archives and Records Administration
NARS	U.S. National Archives and Records Service
NAS	National Academy of Sciences
NASA	U.S. National Aeronautics and Space Administration
NASDA	Japan’s National Space Development Agency
NBS	U.S. National Bureau of Standards
NCSA	National Center for Supercomputing Applications
NEDLIB	Networked European Deposit Library
NetCDF	Network Common Data Form
NHPRC	National Historical Publications and Records Commission
NIC	Nursing Intervention Classification
NISO	National Information Standards Organization
NIST	U.S. National Institute of Standards and Technology
NLA	National Library of Australia
NLM	U.S. National Library of Medicine
NMI	NASA Management Instruction
NOAA	U.S. National Oceanic and Atmospheric Administration
NOST	NASA Science Office of Standards and Technology
NRC	National Research Council
NSF	U.S. National Science Foundation

NSIDC	National Snow and Ice Data Center
NSSDC	National Space Science Data Center
NWAD	Naval Warfare Assessment Division
NWI	New Work Item
OAIS	Reference Model for an Open Archival Information System
OCLC	Online Computer Library Center, Inc.
ODL	Object Description Language
OMG	Object Management Group
OMT	Object Modeling Technique
OOD	object-oriented design
OOP	object-oriented programming
OOSE	Object-Oriented Software Engineering
OPAC	online public access catalog
OSE	Open Systems Environment
OSI	Open Systems Interconnect
OSSA	Office of Space Science and Applications
PAIMAS	Producer-Archive Interface Methodology Abstract Standard
PANDORA	Preserving and Accessing Networked Documentary Resources of Australia
PDI	Preservation Description Information
PDMP	Project Data Management Plan
PDS	Planetary Data System
POSIX	Portable Operating System Interface
PPARC	Physics and Astronomy Research Council
PREMIS	Preservation Metadata Implementation Strategies
PSDD	Planetary Science Data Dictionary
PVL	Parameter Value Language
RAD	Rules for Archival Description
RAL	Rutherford Appleton Laboratory
RI	Representation Information
RID	Review Item Disposition
RLG	Research Libraries Group
RSC	Raytheon Systems Company
SAA	Society of American Archivists
SAE	Society of Automotive Engineers
SC	subcommittee
SDO	standards development organization
SDPS	Science Data Processing Segment
SDSC	San Diego Supercomputer Center
SERC	Science and Engineering Research Council
SFDU	Standard Formatted Data Unit
SIP	Submission Information Package
SOMO	Space Operations Management Office
SPDS	Science Data Processing Segment
SSDOO	NASA Space Science Data Operations Office
SSSC	Storage System Standards Committee

SSSWG	IEEE Computer Society Storage System Standards Working Group
STX	ST Systems Corporation
TAM	technology acceptance model
TC	Technical Committee
TCP	Transfer Control Protocol
THIC	Tape Head Interface Committee
UAF	underlying abstract form
UK	United Kingdom
UKOLN	UK Office for Library Networking
UML	Unified Modeling Language
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNI	Ente Nazionale Italiano di Unificazione (Italian National Standards Body)
UNICODE	Universal Code
URL	Uniform Resource Locator
URN	Uniform Resource Name
U.S.	United States of America
USGS	U.S. Geological Survey
W3C	World Wide Web Consortium
WAN	wide area network
WDC	World Data Center
WG	working group
WP	work package
WWW	World Wide Web
XML	Extensible Markup Language
Y2K	Year 2000
ZBR	zero-based review

ABSTRACT

I report on a multi-method case study of the development of a standard called the Reference Model for an Open Archival Information System (OAIS), which describes components and services required to develop and maintain archives in order to support long-term access and understanding of the information in those archives. The development of the OAIS took place within a standards development organization called the Consultative Committee for Space Data Systems (CCSDS), whose formal purview is the work of space agencies, but the effort reached far beyond the traditional CCSDS interests and stakeholders. It has become a fundamental component of digital archive research and development in a variety of disciplines and sectors. Through document analysis, social network analysis and qualitative analysis of interview data, I explain how and why the OAIS development effort, which took place within a space data standards body, was transformed into a standard of much wider scope, relevant to a diverse set of actors.

The OAIS development process involved substantial enrollment of resources from the environment, including skills and expertise; social ties; documentary artifacts; structures and routines; physical facilities and proximity; and funding streams. Enrollment from the environment did not occur automatically. It was based on concerted efforts by actors who searched for relevant literature, framed the process as open, and promoted it at professional events. Their acts of participation also helped to enroll resources, contributing to what structuration theory calls the signification and

legitimation of the Reference Model, i.e. enactment of what the document means, and why and to whom it is important. Documentary artifacts were most successfully incorporated into the OAIS when they were perceived to support modularity and to be at an appropriate level of abstraction. The content of the Reference Model was subject to stabilization over time, making changes less likely and more limited in scope. A major factor in the success of the OAIS was the timing of its development. Actors within several streams of activity related to digital preservation perceived the need for a high-level model but had not themselves developed one. At the same time, several actors now felt they had knowledge from their own recent digital archiving efforts, which could inform the development of the OAIS. This study has important implications for research on standardization, and it provides many lessons for those engaged in future standards development efforts.

CHAPTER 1 – DEVELOPMENT OF THE OAIS REFERENCE MODEL: AN INTRODUCTION AND RESEARCH PROPOSAL

> *Although tedious and obscure, negotiations over standards are among the most complex and important political arenas of modern societies, with myriad institutional, financial, symbolic, and practical dimensions.*
>
> - Paul Edwards, 2004

1.1 An Unlikely Standards Story

In this study, I investigate the development of an international standard, the Reference Model for an Open Archival Information System (OAIS), which describes the components and services required to develop and maintain archives in order to support long-term access and understanding of the information in those archives. An essential insight from Abbott (1988) is that the mapping between (1) problems or tasks that need to be addressed in the world and (2) the sets of actors responsible for addressing those problems or tasks, is neither absolute nor static. Dramatic changes in the "objective foundations" of the environment – the widespread use of digital technologies to create, share, manage and preserve information objects – have created a new space of work activity, and actors in existing streams of activity consequently must redefine and attempt to reassert their distinct roles within this new environment. As the most high-level, conceptual and persistent form of standards, reference models have the opportunity to serve as what Abbott calls abstractions, particularly when those abstractions define areas of activity that span the boundaries of existing arenas of work, or what I will call "streams of activity."

Several streams of activity have been facing issues related to digital preservation for much of the twentieth century. The streams of activity dealing with parts of the problem often developed their own distinct forums (journals, conferences, consortia) and sets of funding mechanisms (government budget areas, research agendas, foundation support), though the past decade has seen an increasingly recognition by actors in the various streams of activity that they share common issues and concerns.

The development of the OAIS demonstrates what structuration theory (Giddens, 1979, 1984) calls the duality of structure. As a set of abstractions, the OAIS has both reflected pre-existing notions and helped to define new notions about the emerging area of work related to the long-term preservation of digital objects. Actors[1] have drawn on the standard as a resource to produce, reproduce, change, and mobilize the professional structures associated with digital preservation work. While most literature on information and communication technology (ICT) standards development focuses on how standards can support (or fail to support) the direct interchange or coordination between a relatively narrow set of actors or artifacts (e.g. protocols for exchange of data between applications residing on different hardware platforms, data content standards to support federated search across distributed databases), the OAIS acts at a much higher technical and social level of abstraction.

The development of the OAIS took place within a standards development organization (SDO) called the Consultative Committee for Space Data Systems (CCSDS), whose formal purview was specifically support for study of the terrestrial and space environments. However, the OAIS development effort took on a much wider

[1] In this study, I use the term "actor" for an entity to whom I attribute agency. This term is often shorthand for the phrase "individual or organization," similar to the legal notion of "person."

scope than one may have reasonably predicted, given its CCSDS origins. The OAIS development process also ultimately involved and gained visibility among a much broader set of stakeholders than simply members of the CCSDS. This study is driven by the following research question:

> *How and why was the OAIS development effort, which took place specifically within a space data standards body, transformed into a standard of much wider scope?*

1.2 Why Study the OAIS as a Case?

In this section, I explain why the development of the OAIS is such a compelling and potentially fruitful case to study. First, the area of practice to which the OAIS applies – development and maintenance of archival repositories of digital resources – is growing in prominence and importance. Second, development of the OAIS has been a highly visible and influential set of activities, as evidenced by its frequent discussion in publications, reports and research agendas. Third, work on digital preservation has been going on for several decades in an uncoordinated fashion, but those involved in this work have only recently begun to treat it as a distinct area of work that cuts across existing professional boundaries. Fourth, the OAIS development process has crossed the boundaries of several existing organizations and streams of activity. In short, study of this development process provides a unique opportunity to investigate a microcosm of structuration activity in an area of work that is rapidly growing in both prominence and importance.

1.2.1 Growing Importance and Prominence of Digital Preservation Work

As a growing volume of materials are being created and used digitally (Lyman and Varian, 2003), the long-term preservation of those materials is increasingly important. Digital preservation has received considerably more prominence in recent years, gaining the attention of entities such as national libraries, national archives, the European Commission, U.S. National Science Foundation (NSF), Deutsche Forschungsgemeinschaft (DFG - German Research Foundation), and the Joint Information Systems Committee (JISC) in the UK. It has come to be recognized as a legitimate and essential area of research and development.

1.2.2 Visibility and Influence of the OAIS

Even before it had reached any formally approved status within the CCSDS or International Organization for Standardization (ISO), the OAIS received considerable attention from those engaged in digital preservation research and development. Evidence of this can be found in the hundreds of sources identified in Appendix 3 – English Language Literature Citing or Discussing the OAIS. Over the past several years, the OAIS has come to be a widely assumed basis for research and development on digital archiving. Conference papers, articles and reports that present findings on digital archives are generally expected to base their work on the OAIS, indicate how their contributions can be mapped to it or explain why they have not done so.

The OAIS has become “the reference model of choice of those involved in digital preservation worldwide” (Greenstein and Smith, 2003). OAIS-compliance has been a stated fundamental design requirement for major digital preservation and repository development efforts at the U.S. National Archives (NARA), U.S. Library of Congress (LC), British Library, National Library of France (BnF), National Library of the Netherlands (KB), the Digital Curation Centre (DCC) in the UK, Online Computer Library Center (OCLC), the JSTOR (Journal Storage) scholarly journal archive, as well as several university library systems and space agencies. The OAIS is playing prominently in discussions of future funding efforts by both NSF and JISC in the UK. The OAIS has also served as the basis for several very prominent digital preservation metadata initiatives, including CEDARS (CURL Exemplars in Digital Archives), NEDLIB (Networked European Deposit Library), and two joint Research Libraries Group (RLG) / OCLC efforts – the Working Group on Preservation Metadata and then the Preservation Metadata Implementation Strategies (PREMIS) Working Group. RLG and OCLC have also jointly developed guidance on attributes of trusted digital repositories, which builds off of the OAIS. One of the earliest activities of the Digital Preservation Coalition (DPC) in the UK after its formation in 2001 was to develop, along with the British National Space Centre (BNSC), a seminar to discuss and "raise the profile of" the OAIS. The CCSDS is undertaking efforts to developed follow-on standards based on the OAIS, starting with the *Producer-Archive Interface Methodology Abstract Standard* (PAIMAS), which reached Blue Book status in December 2003. RLG and NARA formed a Digital Repository Certification Task Force, whose efforts are explicitly tied to the OAIS and intended to contribute to the ISO Archiving standardization efforts; and an initiative by the Center for Research Libraries (CRL) is extending the RLG/NARA certification work, with funding from the Andrew W. Mellon Foundation. A large number of other research and development projects are either based on or claim conformance to the OAIS.

1.2.3 Increasing Intersections Between Streams of Activity

Digital preservation has long been an area of concern for those responsible for repositories of digital objects. Data mismanagement, technological dependency, media degradation and technological obsolescence have all threatened the long-term accessibility of resources stored in digital formats. As described below, actors involved in various streams of activity attempted to address these issues, but many of their efforts were carried out independently. Both during the years immediately preceding and the years during the OAIS development effort, participants in digital preservation work increasingly came to recognize that they were addressing similar issues.

1.2.4 OAIS as Case of Standardization Crossing Streams of Activity

The OAIS was initially developed to address the needs of a specific subset of organizations responsible for the ongoing management of collections of digital objects. It is a high-level characterization of the functions and entities that should be present in such repositories. Since this standardization effort was first publicly announced, it has received considerable attention from actors taking part in work related to digital preservation. The prominence of the OAIS is evidenced by references in a variety of publications, reports, conferences and professional meetings. The OAIS has contributed "a common language and concepts for different professional groups involved in digital preservation and developing archiving systems" (Beagrie, 2003, p. 45).

1.2.5 Case of the Full Standardization Process

The OAIS was developed by the CCSDS and was then published as an ISO International Standard in February 2003. The OAIS is thus a case of successful collaborative standards development. (Questions of successful adoption and implementation of the standard are outside the scope of my study, but they present promising areas for future research.) The formal development process also provides clear boundaries around the scope of my study.

1.3 Setting the Scene – Context of OAIS Development

The technical complexities involved in digital preservation relate primarily to technological dependency. A document stored on an analog medium such as ink on paper can be read directly with the human eye. Accessing and using a document stored as a digital object, however, requires the coordinated operation of various hardware and software components (e.g. storage medium, peripheral devices, operating system, device drivers, application software). Because of innovations in the information and communication technology industries, these components quickly become obsolete and unavailable. Future access and use of digital objects that depend on current technology raises issues of what Hedstrom (2001) calls "temporal interoperability."

1.3.1 Streams of Digital Preservation Activity before OAIS Effort Began

The challenges associated with digital preservation are not purely technical. In order for digital archives to be sustainable over time, the actors responsible for the archives must have appropriate expertise, resources, and political/institutional mandate to carry out the work required. Given the cost and complexity of digital archives, as well the potential to exploit the rich sets of relationships across individual collections, coordination of work across social boundaries (institutional, regional, disciplinary, organizational and professional) is also important.

In the 1950s, 1960s and 1970s, organizations began increasingly to rely on collections of computer-dependent data. Several streams of activity gradually emerged to address parts of the digital preservation problem, but there was often little communication or coordination across the streams. Two trends that began in the 1960s and 1970s, but became much more prominent during the 1980s and early 1990s, were (1) actors with long traditions of preserving physical artifacts (e.g. archivists, librarians, museum curators) increasingly recognized that information which fell within the scope of their responsibility was now digital, and (2) actors with long traditions of managing computer-dependent data sets (e.g. scientific data center personnel, corporate information technology managers) increasingly recognized that information which fell within the scope of their responsibility had long-term preservation value. The effort to development the OAIS came at a time when the separate streams of activity were making important progress but they were only beginning to identify points of intersection between the streams.

1.3.1.1 Care and Properties of Physical Media

One area of research relevant to digital preservation has addressed the aging and deterioration of electronic storage media and the appropriate conditions for minimizing these processes (Bertram and Eshel, 1979; Bertram and Cuddihy, 1982; Bertram and Stafford, 1980; Brown, Lowry and Smith, 1982, 1983, 1986; Byers, 2003; Cuddihy, 1976, 1980; "Digital-Imaging and Optical Digital Data," 1994; Eilers, 1969; Geller, 1967, 1983; Hariharan, 1999; Higashioji and Bhushan, 2001; Nelson, 1966; Oudard, 1991, 1992; Radocy, 1957, 1959; Saffady, 1985, 1989, 1990, 1991; Van Bogart, 1995; Westmijze, 1953, p.71-81; Williamson, 1991; Vos, et al, 1994; Zhao and Bhushan, 1998). The studies have been carried out within public institutions, such as national research institutions, laboratories responsible for large data sets, vendors of storage technology and the U.S. National Bureau of Standards (NBS), which is now the National Institute of Standards and Technology (NIST). This work has never been at the core of the electrical and electronic engineering professions, but it has continued to serve as a notable part of the periphery, with a small but steady stream of publications appearing in publications such as *IEEE Transactions on Magnetics* (e.g. Cuddihy, 1976, 1980; Bertram and Cuddihy, 1982; Zhao and Bhushan, 1998; Higashioji and Bhushan, 2001; Vos, et al, 1994) and the *Journal of the Audio Engineering Society* (e.g. Radocy, 1957, 1959; Eilers, 1969; Bertram and Stafford, 1980).

1.3.1.2 Hardware and Software Interoperability

Accessing the bits off of a physical medium addresses only one small part of the digital preservation problem. Use and understanding of those bits requires the coordinated operation of various hardware and software components. For several decades, computer scientists and electrical engineers have been actively confronting issues related to the interoperability of hardware and software components over time. The concepts of backward compatibility and legacy systems have served as powerful abstractions for both researchers and vendors in the computer industry. A technology that is backward compatible is "able to share data or commands with older versions of itself, or sometimes other older systems, particularly systems it intends to supplant" (Howe, 2003). A legacy system is "a computer system or application program which continues to be used because of the cost of replacing or redesigning it and often despite its poor competitiveness and compatibility with modern equivalents" (Howe, 1998).

The initiative that most decisively introduced interoperability across generations of hardware into the purview of computer scientists was the System 360 development by

International Business Machines (IBM) in the 1960s. One of the most widely recognized innovations of the System 360 architecture was that it allowed IBM to release and support an entire family of computers -- targeted at different segments of the market -- that all interoperated with each other. However, System 360 also included code that could emulate hardware and thus supported software and data files created on earlier IBM hardware (McCormack, Schansman and Womack, 1965; Pugh, Johnson and Palmer, 1991; Tucker, 1965). Many software and hardware vendors have followed IBM's lead, building backward compatibility into their products, in order to perpetuate lock-in to their line of products while also supporting an easy transition to their latest offerings. For example, Intel has developed its microprocessors in ways that allow them to emulate the instruction sets of earlier Intel microprocessors (Halfhill, 1994; Noyce and Hoff, 1981). Developers of new microprocessor architectures also test and validate their new designs by emulating them on existing hardware before they commit to the costly process of fabrication.

At the same time that producers were applying and refining the backward compatibility concept, expertise began to develop on the user[2] side about how to address the problems associated with data residing on legacy systems within organizations. For consumers, dependence on existing hardware not only introduced economic costs of lock-in to specific vendors, but it also raised the prospects of data residing on systems whose producers went out of business or failed to provide any further support for those systems. Computer scientists and engineers on the user side developed approaches to promote

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[2] I am using the term "user" here much as Cargill does in his presentation of a spectrum of standards. Users are the administrators, integrators and maintainers of information technology within specific organizations. This group is distinct from the end users who make use of the technology in their daily work.

“machine independence” (Halpern, 1965). This included computer-supported translation between low-level languages, in order to mitigate the effects of platform dependency (Gaines, 1965; Wilson, 1965).

During the 1980s and 1990s, there was an increasing emphasis in the computer industry on portable and reusable code. For some types of software, developers were often willing to pay the price of increased development time or degradation of performance in order to increase the chances that their software could be used on a wide variety of hardware platforms. This resulted in work on virtual machines, including the prominent Java Virtual Machine (JVM). The Java language is also a prominent example of a trend toward object-oriented design (OOD) and object-oriented programming (OOP). Object-oriented approaches had their roots in the introduction of the Simula language in 1967 and then the development of the Smalltalk language throughout the 1970s. Numerous language and development environments have been developed since then, with the most prominent languages in the 1980s and 1990s being C++ and Java. As its name implies, OOD is based on objects, which can contain not only data but also the methods to manipulate the data. A class is a category of objects, which defines all the common properties of the objects that belong to it. Messages are units of information that can be passed between classes and objects, and interfaces are the points of contact between objects. Other important concepts of OOD are inheritance, through which an object in a class can take on the data and methods of any other classes of which it is a subclass, and encapsulation, which is an object's hiding of its data structures and method implementation details from other objects.

As development using OOP became more prevalent throughout the 1980s, there was an increasing recognition that the potential advantages of OOD would not simply happen automatically. Starting in about the early 1990s, a number of experts began broadening their focus. Rather than identifying OOD as only a programming methodology, they argues that one should see it as a much broader approach to analyzing and then addressing organizational processes and needs (Jacobson et al, 1992; Graham, O'Callaghan and Wills, 2001). This implies an object-oriented approach to all phases of the product development lifecycle and building systems out of relatively self-describing, reusable units of information. Although various authors within the OOD literature used different words for these reusable units of information, one that fed into the OAIS was "package" (Jacobson et al, 1992; Martin, 1996).

A related set of efforts in the early to mid 1990s involved the development of a common, industry-wide notation. Not only should different pieces of code be able to share objects but different individuals working on different aspects of the same system should be able to share a similarly represented conceptions of the system. Ideally, those working on new systems could also reuse code from existing ones when appropriate, since they would be using this same meta-model. The three chief advocates for the idea of a meta-model – Ivar Jacobson, Jim Rumbaugh and Grady Booch – had each developed their own modeling approaches (Booch '93, OMT-2 and OOSE). They joined forces to work out one unified standard, and the resulting product, Unified Modeling Language (UML), was submitted to and then approved by the Object Management Group (OMG) in 1997. UML not only acted as a useful set of abstractions for conveying the fundamental concepts of OOD, but it also served as a tool that designers could use to represent their own abstractions. As I discuss later, participants in the development of the OAIS used Object Modeling Technique (OMT), and then UML, to represent the components of the Reference Model.

One set of actors particularly concerned with machine-independence has been those responsible for very large data sets (originally on the order of Terabytes but now much larger). When developing and maintaining the systems that manage these large data sets, which are often distributed across various locations, it is essential to avoid dependence on one specific storage technology or operating system. In the 1960s and 1970s, this work came to be associated with the label Mass Storage Systems (MSS). The first IEEE Conference on Mass Storage Systems was in 1974. The U.S. National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) began a series of similar conferences in 1991. In 1998, the two series merged into one (Jones, 2003).

A subset of system and database administrators – particularly those working for large organizations that maintained collections of digital objects over many years – also began to develop expertise in the recovery of both data and functionality from legacy systems of all sizes. Important work related to legacy data recovery was periodically reported at professional conferences, such as the International Conference on the Entity-Relationship Approach (now the International Conference on Conceptual Modeling), which began in 1979, and the Conference on Software Maintenance, a series initiated in 1983. However, such work was closely tied to the details of specific technological and organizational contexts and was thus generally not framed as part of a larger endeavor to address long-term preservation.

The literature discussing legacy data and code recovery was relatively diffuse until the 1990s, when a number of articles published by the IEEE (Institute of Electrical and Electronics Engineers) (Bennett, 1995; Bray and Hess, 1995; Chikofsky and Cross, 1990; Dedene and De Vreese, 1995; Griss and Wosser, 1995; Merlo, et al, 1995; Rugaber, Ornburn and LeBlanc, 1990; Sneed, 1995; Wong, et al, 1995) and the Association for Computing Machinery (ACM) (Aiken, Muntz and Richards, 1994; Markosian, et al, 1994; Ning, Engberts and Kozaczynski, 1994; Premerlani and Blaha, 1994; Quilici, 1994; Waters and Chikofsky, 1994) contributed to an emerging category of work related to issues of legacy data and systems. This category did not have a home within a single existing profession, but was instead associated with electrical engineers, computer scientists, and a more recent entrant, management of information systems (MIS) (Brodie and Stonebraker, 1995). In 1993, the IEEE hosted the first Working Conference on Reverse Engineering, which also helped to signify and legitimate long-term data maintenance as a distinct area of work activity for IEEE members (for a historical overview, see Davis and Aiken, 2000).

1.3.1.3 Long-Term Management of Institutional Archives and Personal Papers

The stream of activity related to long-term institutional management and preservation of unpublished records generated by individuals and organizations has traditionally been the responsibility of the "archival profession." The actors within this stream of activity have generally been represented by professional associations associated with their own countries – e.g. in the United States, the Society of American Archivists (SAA) since 1936 – and the International Council on Archives (ICA) at the international level since 1948. In North American since around the end of World War II, the allied occupation of “records management” has also developed specifically to address the management and disposition of active and semi-active records (Webster, 1999).

For the past several decades, members of the archival profession have adopted computers in support of several areas of their work, such as administration, management and description of materials, but their efforts to take custody of and preserve archival materials in digital form have been relatively limited. According to Gilliland-Swetland (1992), “the first article relating to computers published in archival periodical literature" was Lawson (1948). By the late 1970s and early 1980s, the archival literature included many reports on the actual and potential use of computers to support the internal operations of archives (Hickerson, Winters and Beale, 1976; Hickerson, 1981; Arad and Olsen, 1981; Kesner and Hurst, 1981; McCrank, 1981). For more than three decades (see Kaplan, 2003), numerous articles and reports have called for members of the archival profession to revise their theories and practices, and take a more active role in order to address the management and preservation of digital objects (Bearman, 1989, 1994a, 1994b; Bearman and Hedstrom, 1993; Dollar, 1978, 1992, 1993; Fishbein, 1972; Hedstrom, 1984, 1989, 1991, 1995; Kesner, 1983, 1984-85, 1985; Stielow, 1992; “Taking a Byte out of History,” 1990).

Despite these numerous calls for action, institutional archives and manuscript repositories have generally not taken custody of digital objects. The U.S. National Archives and Records Administration (NARA) has been taking on data sets since the 1960s (Ambacher, 2003), but the volume of such acquisitions has been relatively small, compared to that of the data centers described elsewhere in this chapter. Starting in the 1980s, a handful of state archives in the U.S. – most notably Wisconsin, Kentucky and

New York – began taking custody of sets of digital objects, but those initial efforts were not followed by substantial digital acquisition or digital preservation activities in any of the states. In the mid-1990s, the national archives of Finland, Iceland and the UK experimented with various approaches to contracting out their digital preservation activities (Sleeman, 2004).

Within the literature of the archival profession, discussions of the management and preservation of digital objects are often embedded within larger debates about changes in the profession's scope, orientation and identity (Bantin, 1998; Bearman, 1989, 1994b; Bearman and Hedstrom, 1993; Brown, 1996; Cook, 1991-92, 1994; Cox, 1994, 1995, 2000). A great deal of attention is devoted in the literature of the archival profession to the issues of what to call the category of individuals who carry out this work (e.g. archivists; archivists and records managers; records professionals; information professionals; knowledge managers; digital librarians; data archivists; repository managers) and how to identify the academic discipline(s) that provide the theories and principles that guide the work (e.g. archival administration; archival science; archivistics; diplomatics; archivy; library science; historiography). While these arguments may appear to be of little consequence in themselves, they reveal important shifts in the signification structures of professional work. Phillip Bantin characterizes electronic records[3] work in the 1990s as tied to "intense and passionate debate" about questions such as the following: "What do archivists and records managers contribute to society? What is their relationship to other information management professionals?" (2001, p. 16)

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[3] Within the archives literature, the phrase "electronic records" (and earlier, machine-readable records) can be seen as a superset of the concept of digital preservation. In addition to long-term access to digital objects, electronic records also includes the definition and application of formal records management requirements for both active and inactive records.

As symbol processing devices, computers require very explicit instructions. In order to inform the development and operation of computer systems, professional abstractions must be specified in more detail than when they are intended solely to guide the activities of human actors. This reflects a maxim offered by Brian Cantwell Smith: "no computation without representation" (1996, p.815). The emergence of electronic records, therefore, has had the potential to serve as catalyst for archivists to translate existing professional principles and heuristics into more formally detailed abstractions. Two research projects in the 1990s, one at the University of Pittsburgh (Duff, 1996, 1998) and the other at the University of British Columbia (Duranti, Eastwood and MacNeil, 1997; Duranti and MacNeil, 1996), developed formalizations of established abstractions in the archival profession, particularly evidence, record, and authenticity. The former project produced functional requirements, production rules and a metadata specification; the latter generated an entity model.

One conference series, called Managing Electronic Records (MER), has been hosted by Cohasset Associates since 1992. This is the primary forum dedicated exclusively to electronic records management. MER has consistently featured speakers on digital preservation strategies, but this has been a relatively peripheral topic of a conference that focuses primarily on short-term records management efficiency, legality, and risk management.

1.3.1.4 Social Science Data Archives

Starting in the 1930s and 1940s, many research projects generated data sets on machine-readable (first punch cards, then magnetic and optical) media that were of potential long-term interest to social science researchers. Several of these became the basis of social science data archives. The actors responsible for these archives, and social scientists who hoped to make use of them, began to recognize that they had many common concerns. The International Social Science Council (ISSC) hosted the First Conference on Social Science Data Archives in 1962. The second international conference in 1964 included reports on technical practices such as documentation generation and tape cleaning (Rokkan, 1966). By 1966, one data archivist was able to generate a list of numerous operating repositories, and lay out the specific types of skills and functions involved in their administration (Bisco, 1966). That same year, the ISSC formed a Standing Committee on Social Science Data Archives, and at the third international conference, enough common ground had already been established for the discussions to focus on specific technical issues such as "data cleaning, data formatting, handling missing data, retrieval systems, and access rules" and "securing technical compatibility for interarchival data exchange" (Scheuch, 2003, p. 389).

As data archivists continued to define their work as a distinct stream of activity, several new organizations emerged to represent the institutions responsible for this work. The Council of European Social Science Data Archives (CESSDA) was founded in 1976, and the International Federation of Data Organisations (IFDO) was founded in 1977. CESSDA came to emphasize "substantive issues in running data archives," while IFDO was concerned with "policies on cooperation between data organizations" (Scheuch, 2003, p. 392). Another significant milestone was the formation in 1976 of the International Association of Social Science Information Service and Technology (IASSIST), whose conferences grew out of the 1974 Conference on Data Archives and Program Library Services. The literature on migration of data from obsolete media has benefited from the efforts of data archivists (Green, Dionne and Dennis, 1999), and the preservation of digital resources has been a continuing (though not central) topic of discussion in the *IASSIST Quarterly* (Conrad, 1994; Eaton, 1994; Oudard, 1991; Robbin, 1977).

1.3.1.5 Earth and Space Science Data Archives

The following section does not provide a comprehensive account of earth and space science data archive activities but instead provides a brief summary of international efforts and then focuses on the data management and preservation efforts of NASA. This is because NASA was the organizational actor[4] most responsible for the development of the OAIS Reference Model and its organizational context was the most influential source of material for the Reference Model document.

According to Duerr, et al (2004), "scientific data as a discipline distinct from document preservation or records management…is a fairly recent concept." In 1952, the International Council of Scientific Unions (now called the International Council for Science) proposed an International Geophysical Year (IGY), which would be a series of globally coordinated geophysical observations and research activities taking place between July 1957 and December 1958. The World Data Center (WDC) system was initiated in 1955 to maintain and distribute data collected as part of the IGY. The WDC system was influential in the establishment of two trends: a "focus on the preservation and distribution of raw data as opposed to the interpretation of those data" and an

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[4] In this study, I use the term "organizational actor" to indicate an actor composed of two or more individuals. This can be as small as a couple and as large as an institution, profession or nation. For the purposes of this document, I most often used the term to refer to project teams, divisions, departments, agencies, professional associations, universities, nonprofit organizations or firms that were directly involved in or otherwise influenced the development of the OAIS.

organization based on separate data centers for different disciplines (Duerr et al, 2004, p.102).

According to one report, since its creation in 1958, "NASA has been primarily an agency devoted to the acquisition and communication of information about the Earth, the planets, the stars, and the universe." (Long and Healy, 1980, p.13) By 1967, the GSFC, which was responsible for maintaining data from earth-orbiting scientific satellites, reported that storage of these data (140,000 reels of magnetic tape and accumulating approximately 35,000 tapes per year) was becoming “a very significant problem” (Holmes et al, 1967, p.1). GSFC had begun work in 1964 to “develop an archival system” to meet its needs, but two attempts to procure a system were unsuccessful. This work, however, did yield concrete representations of the requirements for an archival system. GSFC produced a “data archive functional diagram,” intended to represented “two basic processes”: “the introduction of raw data into the archive and the withdrawal of data in response to retrieval requests” (p.6). The diagram (see Figure 1) includes eight boxes – Data Requests and Retrieval; Computer for Indexing and Retrieval; Store; Reading System; Data Tape Sources; Digital Data Archive Writing System; Verify; and Rehab[ilitation] of Tape – and arrows indicating relationships between them.

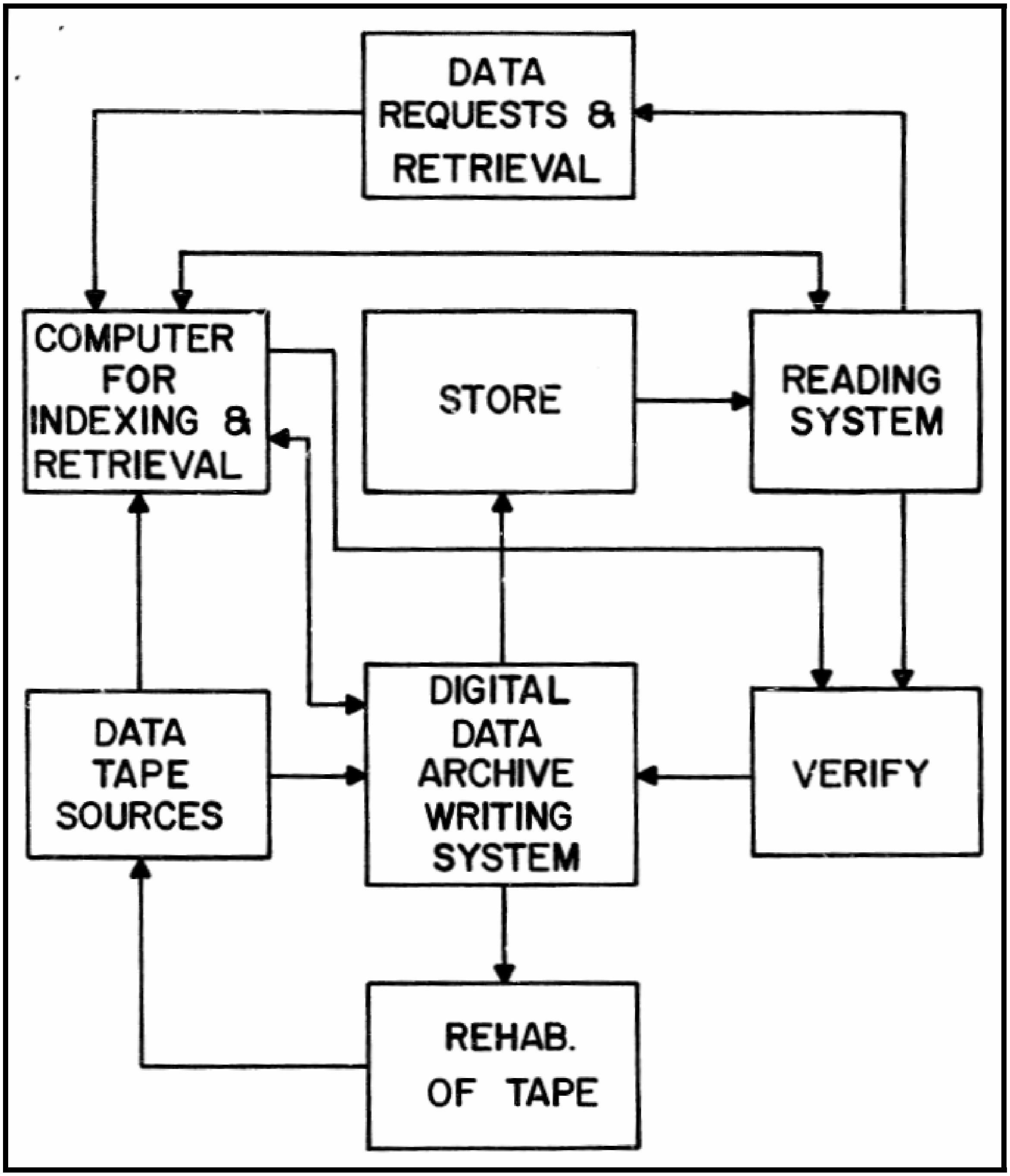

Figure 1 - 1967 Goddard "Data Archive Functional Diagram"

[Source: Holmes, Poland and Demmerle, 1967, p.12]

In 1966, NASA established the National Space Science Data Center (NSSDC) at GSFC as NASA's long-term archive for space science mission data. Over the years, NASA also developed a widely distributed set of wavelength-specific data centers for astronomy data, topic-specific Distributed Active Archive Centers (DAAC), and Regional Planetary Image Facilities.

Although NASA developed its own infrastructure for storing and managing data sets generated by the research it supported, NASA's history of data management has been strongly influenced by a tradition of individual scientists or groups of scientists having significant responsibility for the care and documentation of the data generated from their own studies. Scientists were often granted temporary exclusive rights to access data from studies they designed, during a "proprietary period." This was intended to provide scientists with an opportunity to publish results before they then transferred copies of the data to NASA. The principal investigators often "dragged their feet" on transferring data to NASA or submitted it in a form that was not very useful to other researchers (Wallace, 1999, p.77). A 1977 U.S. General Accounting Office (GAO) report indicates that lack of contract enforcement, resources for investigators and NSSDC staff all contributed to this problem ("More Emphasis Needed," 1977).

In 1977-1978, a NASA Study Group on Machine Intelligence and Robotics, chaired by Carl Sagan, conducted a study of the current and potential future use of advanced information and communication technologies at NASA. The Study Group concluded that NASA was "5 to 15 years behind the leading edge in computer science and technology" and that its "use of computer science and machine intelligence has been conservative and unimaginative." (Long and Healy, 1980, p.15) The Study Group recommended that “a task group should be formed to examine the desirability, feasibility, and general specification of an all-digital, text-handling, intelligent communication system for the transfer of information between NASA Centers” (Long and Healy, 1980, p.16).

On May 2, 1978, NASA issued NASA Management Instruction (NMI) 8030.3A, "Policy Concerning Data Obtained from Space Science Flight Investigations," which established a requirement for each space flight project to develop a document called the Project Data Management Plan (PDMP).

A 1980 study sponsored by NASA and the American Society for Engineering Education (ASEE) indicated that NASA’s data handling practices of the time could not scale up to meet the need of increasingly large and complex data sets. The “amount of data made available by NASA missions is more than scientists can easily sift through in times on the order of a decade or less.” The study states that “the raw data are not accessible in a timely and convenient manner” and “most potential users do not have the resources to extract useful information from the raw files.” Rather than retrieving and storing all of the data that a sensor can possibly generate, the study recommended an approach called “goal-oriented data collection,” which is based on more active selection, processing, organization and management of data (Long and Healy, 1980, p.13)

In 1982, the National Academy of Sciences (NAS) chartered the Committee on Data Management and Computation (CODMAC). In the 1980s, CODMAC issued a series of reports (in 1982, 1984 and 1986), which included recommendations related to better scientific involvement, creation of PDMPs, adoption of appropriate formats, proper facilities, adequate resource commitment, and development of discipline-specific archiving systems.

In late 1985, NASA's Associate Administrator for Space Science and Applications requested a study by the National Research Council (NRC). The NRC's Board on Telecommunications and Computer Applications established a Committee on NASA Information Systems in early 1986 to perform the requested study. The Committee reported that

> in most cases the data [from past NASA space science and applications missions] remains in its original form and format, and it resides in data archives and is accessed by information systems that were developed for specialized purposes that are not compatible with systems being used today or, in some cases, with one another (NRC Committee on NASA Information Systems, 1987).

In 1986, NASA organized a workshop related to the requirements for an Astrophysics Data System (ADS). The report generated from this workshop, which was created by Gael Squibb – who would later propose the New Work Item that ultimately became the basis for the OAIS development effort – called for a data system to connect the various mission centers that managed astrophysics data. The report recommended that system should be distributed, so that data sets and the expertise associated with them could be co-located, while a "Master Directory" would allow users to locate data within the system. The report also indicated the importance of moving data from these active data centers to a more persistent archival environment after projects were completed (Murray, 1990).

An April 1987 GAO report presented "concerns by the scientific community and NASA representatives" in several areas, including "NASA's processing, distribution, and archiving of science data" ("Space Operations: NASA's Use of Information

Technology," p.6). The late 1980s saw activities following onto the Squibb report. The distributed Planetary Data System (PDS) was created in 1989, based on the perception that the NSSDC could not address needs for "curation, access, and distribution of planetary data" on its own (Evans, 1984, p.5).

During the late 1980s and early 1990s, NASA, the European Space Agency (ESA) and the Science and Engineering Research Council (SERC)[5] Physics and Astronomy Research Council (PPARC) in the UK conducted a project called the IUE Final Archive. The International Ultraviolet Explorer (IUE) was a satellite that had been launched in 1978. Starting in 1989, a committee met to identify the requirements for long-term archiving of the data. This involved challenges related to non-standard data formats and the need to include technical documentation that would be understandable to future curators and users of the data. The project produced a series of studies, proposals and recommendations.

In the early- to mid-1990s, one NASA initiative that received considerable internal and external attention was the Earth Observing System Data Information System (EOSDIS) to support a very large-scale, multidisciplinary, international effort to study Earth processes. The system of Distributed Active Archive Centers (DAACs), involving several parts of NASA, National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), and many international partners, would involve the collection, management and distribution of an unprecedented volume of data, and an associated set of design challenges related to mass data storage systems, media and data

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[5] After the SERC was disbanded in 1993, this became the Physics and Astronomy Research Council (PPARC).

format standards (Beers et al, 1991; Kobler and Berbert, 1991; Bedet et al, 1993; Guzek, 1993; Ryan, 1994; Kobler et al, 1995; Schaefer, 1995; Peavey and Behnke, 1996).

In March 1990, the GAO issued a report (Schwartz et al, 1990) entitled “Space Operations: NASA Is Not Properly Safeguarding Valuable Data from Past Missions." The report states:

> Currently, hundreds of thousands of tapes containing space science data are stored under deplorable conditions. Furthermore, NASA needs to improve its management of tape archiving and storage activities. It has not performed an agencywide inventory of its magnetic tapes and, consequently, does not know what data are retained, or may have been lost, nor can it easily identify or retrieve tapes being stored in its centers or at universities. Further, NASA has not enforced federal regulations or developed its own standards for minimum acceptable storage, maintenance, security and quality control, and inventory practices. (p.2-3)

That fall, several members of the GSFC staff presented a conference paper on “A Comprehensive Cost Model for NASA Data Archiving” (Green, Klenk and Treinish, 1990). The authors report a model, based on the experiences of NSSDC, Jet Propulsion Laboratory (JPL), NOAA, and USGS, which is the result of an effort begun more than a year earlier by NASA to “better understand the archiving activity itself and its associated costs.” The model “breaks down the generic archiving functions performed by an archive facility…into its generic components parts.” It presents several concepts and terms later used in the OAIS, including Ingest, Storage, Distribution, Preservation Planning, Producer, Archive/Producer Interface, and Information Package. The conference paper also claims that the adoption of data standards can lead to significant archiving cost savings. The authors state that the cost model was being used by the NSSDC and “several NASA projects.”

In November 1990, the GAO issued another report critical of NASA's data archiving practices, indicating that it was failing to obtain original (as opposed to processed) data and data from many of its operations (Beers et al, 1990). The report also states that, between the issuance of NMI 8030.3A in May 1978 and October 1985, only one mission actually prepared a Project Data Management Plan (PDMP) as required by that policy.

The NASA Office of Space Science and Applications (OSSA) began a Data Management Initiative (DMI) in 1991. It focused on the identification and prioritization of data sets requiring restoration; restoration and archiving of appropriate data; and the assurance of "routine flow of increasing volumes of the right data into the OSSA archive environment." ("State of the Data Union," 1992) The OSSA had six program divisions – Life Sciences; Earth Science and Applications; Solar Systems Exploration; Microgravity Science and Applications; Space Physics; and Astronomy – and each was to develop its own data management strategy and Discipline Data System (DDS).

In January 1992, the OSSA issued a "State of the Data Union." It reports that "recent years have seen a transition in the nature of space science research," including "an increase in the number of multi-agency efforts and international collaborations," "increased use of data beyond the original experiments, greater diversity in the style of research and modes of operation, and a continuity from project operations to post-mission research. Space missions are becoming much more data intensive than in the past." The document also notes, "Mission lifetimes are increasing, with some expected to last 15 years or longer." The report lays out what it calls the OSSA Data Union, which is composed of the OSSA data management environment and its various stakeholders. One of the four centralized “elements which support the needs of all divisions” is called “data management and archiving.” It indicates the “OSSA’s approach to data access and storage” as the following:

1. Science investigators initially access data from the project data repository.
2. Data then flows from the project data repository to a discipline data archive for broader access by the scientific community.
3. Then the data typically goes to the NSSDC for permanent retention and ongoing access.
4. The NASA Master Directory provides cross cutting information regarding identification and location of all data of OSSA interest. (p.4)

The OSSA issued a new data management policy directive in March 1992. This replaced the policy, NMI 8030.3A, from 1978 discussed above. The new directive states that the PDMP as laid out and required in 8030.3A had been “essentially conceived as a data archiving plan,” but “increasing complexity of NASA science investigations and the volume of data that they generate (among other factors) emphasizes the need for increased emphasis and priority for data management planning early in the project's life.” This 1992 directive more explicitly addresses the entire lifecycle of data. It expands the scope of a PDMP “to include planning for data management throughout the project planning and implementation phases.” The new directive also calls for review processes throughout the lifecycle, including reviews “to determine the state of data and to assure conformance with applicable government standards for data storage” and “an active process to maintain an awareness of emerging applicable technologies, infuse them into its systems, and stimulate new technology development where warranted.” The directive also states:

> National and international standards for media, formats, and communication of data sets shall be used to the greatest extent possible. NASA shall participate in the development and implementation of standards. NASA unique standards shall be used only if adequate national or international standards are lacking. The intent of this policy is to standardize the interfaces between the users and NASA's data and information systems, not to standardize the systems themselves.

The ADS Abstract Service was first demonstrated in 1992 and was put online for general use in April 1993. In February 1994 the service was moved onto the World Wide Web from its original NASA-developed network home (Kurtz et al, 2000, 2005). While this system managed bibliographic data, rather than scientific data sets, it served as a prominent example of developing a system at NASA for widely distributed access.

In March 1993, the OSSA issued an updated version of the 1988 document: "Guidelines for Development of a Project Data Management Plan (PDMP)." That same month, NASA reorganized space science activities, which included the elimination of the OSSA moving its six science divisions into three different offices.[6] In December of that same year, the GAO again issued a report about NASA's data archiving practices. While it cited recent progress, it reported that problems still remained, including failure to review data at temporary storage locations; inadequate budgeting for data archiving; failure to ensure preservation of original data; failure to periodically inspect facilities and sample data quality; and failure of data archiving policies to reflect recent reorganization or the contract with the JPL (Warren, Pettis et al, 1993). Around this time, the GAO also issued three separate reports addressing concerns about the contract provisions, including equipment lending practices, of the JPL (Warren, Degnan et al, 1993, 1994; "NASA

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[6] Earth Science and Applications became Mission to Planet Earth; Space Physics, Solar System Exploration and Astrophysics were combined to form Space Science; and Life Sciences and Microgravity Science and Applications became Life and Microgravity Sciences and Applications.

Procurement: Contract and Management Improvements," 1994). In April 1994, JPL held a three-day Low-Cost Mission Operations Workshop, which was part of a significant shift in orientation at JPL "from one of maximizing science to one of acceptable scientific return on the lowest possible operations cost" (Marino, 1994). One thing that emerged from this workshop was a model for mission operations, which includes 13 distinct functions, one of which is "Archiving and Maintaining the Mission Database" (Squibb, 1995, p.33). An influential actor in the initiative to redefine mission operations throughout NASA, in order to eliminate redundancies, rely more heavily on contractors, and generally contain costs, was Gael Squibb, who was then Manager of the Flight Projects Mission Operations Development Program Office at JPL[7] (Squibb, 1996; Squibb and Heftman, 1996; Squibb, 1997).

In response to the President's budget request for 1996-2000 in January 1995, NASA conducted a zero-based review (ZBR) of its infrastructure. The guidelines resulting from this process indicated that a portion of the NSSDC should be privatized, starting in fiscal year 1996 and completed during fiscal year 1997. (Riegler, 1995)

Also in 1995, the NRC Steering Committee for the Study on the Long-term Retention of Selected Scientific and Technical Records of the Federal Government, Preserving Scientific Data on Our Physical Universe issued its report. The document is intended to advise NARA and federal research and development agencies "on the long-term retention of scientific and technical data, particularly in electronic formats." The report proposes that a National Scientific Information Resource Federation be created to

[7] A February 15, 1997 publication indicates Squibb's job title as NASA Data Services Manager at the NASA Space Operations Management Office (SOMO) (Squibb, 1997).

"apply a strategic data life-cycle management plan to better link the government's existing scientific data holdings and improve public access to those holdings."[8]

1.3.1.6 Management and Provision of Access to Digital Library Collections

Librarians have often adopted new ICTs – microfilm, punch cards, computers – in order to facilitate the management and provision of access to library collections. In the 1970s and 1980s, many libraries developed online public access catalogs (OPACs) and began to actively use third party scholarly and bibliographic databases. The 1990s saw a growing presence of library systems for information discovery on Gopher and the World Wide Web, and the development of innovative collections based on the digitization of existing physical collections.

Those responsible for the design and management of new online library access systems developed unique expertise and capabilities (Greenstein and Thorin, 2002). "Digital libraries" became the label most frequently identified with their collective efforts. A key actor in the formation and promotion of this stream of activity was the NSF (Fox, 1993). In October 1991, the NSF sponsored a Workshop on Future Directions in Text Analysis, Retrieval and Understanding, which generated a set of recommendations for research and development within the framework of a new "Nationwide Electronic Library in Science, Engineering and Technology." Additional NSF-sponsored workshops in July and December of 1992 further elaborated and refined the agenda that had come out of the 1991 workshop. In May, 1995, the Information

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[8] Don Sawyer discusses the findings of this report in his April 24, 1995, "Background Material and Proposal for Addressing a NASA-Led US and International Archiving Standards Effort." No member of the NRC Steering Committee responsible for the "Data on Our Physical Universe" report took part in any ISO Archiving Workshops.

Infrastructure Technology and Applications (IITA) Working Group held a workshop that addressed definitions, roles, infrastructure requirements, research issues and priorities for digital libraries (Lynch and Garcia-Molina, 1995). In September 1993, the NSF, in cooperation with the U.S. Advanced Research Projects Agency (ARPA) and NASA, announced a call for proposals for "Research on Digital Libraries." This Digital Libraries Initiative (DLI) funded six projects from 1994 to 1998. Another important effort was the Computer Science Technical Reports (CS-TR) project, which was funded by ARPA, ran 1992-1995, and involved five universities and the Corporation for National Research Initiatives (CNRI). The architecture that resulted from this project (Kahn and Wilensky, 1995; Arms, 1995; Anderson, Lasher and Reich, 1996) served as the basis for much digital library work that followed.

In the UK, the Joint Funding Council's Libraries Review Group undertook an investigation in 1993, chaired by Brian Follett, which concluded, "The exploitation of IT is essential to create the effective library service of the future." The Higher Education Funding Bodies in the UK then invited proposals for projects under a new Electronic Libraries Programme (eLib) to be managed by JISC. The first set of projects under this program began in the spring of 1995.

Several forums emerged to address this new area of practice. The *First Annual Conference on the Theory and Practice of Digital Libraries* also took place in 1994. The ACM, one of the organizing bodies of the 1994 conference, began formally hosting the series in 1996. In 1995, IEEE began its own *Forum on Research and Technology Advances in Digital Libraries*.[9] Several U.S. organizations formed the Digital Library

[9] The ACM and IEEE series merged in 1999 to become the *Joint Conference on Digital Libraries (JCDL)*.

Federation "to bring together – from across the nation and beyond – digitized materials that will be made accessible to students, scholars, and citizens everywhere, and that document the building and dynamics of America's heritage and cultures" (Digital Library Federation, 1995). The U.S. Government's Information Infrastructure Technology and Applications (IITA) Working Group held a workshop in Reston, Virginia on May 18-19, 1995 to address the research agenda for digital libraries (Lynch and Garcia-Molina, 1995). In July 1995, *D-Lib Magazine*, "a magazine about digital library issues for researchers, developers, and the intellectually curious" (Friedlander, 1995), published its first issue. This online serial was sponsored by the IITA task group of the High Performance Computing and Communications (HPCC) program, and it was produced by CNRI. Several European institutions were also very active in this area of work, and the *First European Conference on Research and Advanced Technology for Digital Libraries* took place in 1997. Early discussions in the digital library forums generally focused on the design and implementation of new systems, rather than ongoing management or persistence of digital collections.

Within the library profession more generally, however, digital preservation was a growing topic of discussion during the 1990s, with the initial catalyst being concerns about electronic journals. Many libraries, particularly those serving large research universities, made a dramatic shift toward electronic subscriptions to periodical publications. As a result, long-term access to these materials was increasingly dependent on both dynamic technology and external organizations. Concerns soon extended to many other types of digital resources for which libraries were increasingly responsible.

In 1994, the Commission on Preservation and Access (CPA) and RLG created a Task Force on Digital Archiving. The Task Force issued a report in 1996, which was frequently cited by subsequent literature on digital preservation. On November 27-28, 1995, as part of the eLib Programme described above, JISC and the British Library sponsored a workshop at the University of Warwick, organized by UK Office for Library Networking (UKOLN) to discuss "options for developing and managing electronic archives," "collection policies for electronic materials," and "preservation policies." According to the report from this workshop, the CPA/RLG Task Force draft report had "acted as a touchstone for the workshop, shaping ideas and prompting discussion (particularly on the applicability of its recommendations in the UK)." (Brindley and MaCartney, 1995, p.1). Despite this considerable intellectual progress on digital preservation issues, there was still a gap in the mid-1990s in research libraries between awareness of technical issues of obsolescence and implementation of available practices (Hedstrom and Montgomery, 1998).

1.3.2 Increasing Prominence of ICT Infrastructure

Several factors in the years leading up to the OAIS development development effort made the importance of standards in supporting the infrastructure that underlies various socially valuable activities particularly salient. Two closely connected factors were the development of widely distributed computer networks and an industry trend toward commercial off-the-shelf (COTS) equipment. Rather than depending on the compatibility of an entire suite of hardware and software from a single vendor, both producers and consumers of computer equipment came to rely on conventions for interchange of data between an increasingly heterogeneous set of components. Both the

ISO – in the form of the Open Systems Interconnect (OSI) Reference Model and related standards such as Government Open Systems Interconnection Profile (GOSIP) – and Internet Engineering Task Force (IETF) – in the form of prominent protocols such as File Transfer Protocol (FTP), Transfer Control Protocol (TCP) and Internet Protocol (IP) – developed layered architectures to which hardware and software producers could conform in order to ensure that their products could interchange data with other products on the Internet. In the early 1990s, the adoption of the World Wide Web resulted in a dramatic increase in the base of consumers who had a stake in seamless interchange of data over computer networks. The World Wide Web Consortium (W3C) formed in 1994 to advance protocols and other standards for the Web.

The increasing ubiquity of computer hardware and software underlying common activities also resulted in a much wider awareness of infrastructure as a concept. Terms such as National Information Infrastructure, Global Information Infrastructure and Public Key Infrastructure became repeated reminders that business, government and even everyday person interactions often depended on a widespread assortment of hardware and software components that usually interoperated without anyone noticing but could cause significant problems when they failed to interoperate. The Year 2000 (Y2K) conversion effort was one very prominent example of this dependence on the growing digital infrastructure (Edwards, 1998).

1.3.3 Standards Development

The literature on the management and preservation of digital objects includes many references to the important role of standards (Walch, 1990). Several authors have identified standards and standardization as important components of professional education of those responsible for managing and preserving digital resources (Gilliland-Swetland, 1993, p. 538-9; Hedstrom, 1993, p. 432; Walch, 1993). In 1992, Dollar recommended that archivists "identify archival functional requirements" and then participate in standards development organizations in order "to ensure that these functional requirements are incorporated into" relevant standards (81). According to Cox (1992), archivists "must convince the information technology standards committees and other organizations that their questions and concerns of preservation, access, and use are relevant and essential to both the information technology vendors and users" (p. 572). Bearman (1994b) presented standards as one of the four "tactics" for achieving the functional requirements for evidence in recordkeeping.

In addition to developing standards, many sources have also suggested the value of adopting standards in order to facilitate long-term access to digital objects. According to one early report on electronic records in the federal government, "Machine incompatibility…will undoubtedly be solved both by standardization and by development of universal conversion machines" (Jacob, 1960, p. 11). Although this prediction seems overly optimistic in retrospect, there is still considerable hope for the role of standards within the digital preservation literature. A federal report entitled "Taking a Byte out of History: The Archival Preservation of Federal Computer Records" (1990), indicated, "Sometimes, files can be readily converted to a format that uses generic software and standard hardware. When this is possible, specific software and hardware are not needed to ensure long-term access" (p. 3). Dollar and Weir (1991) argued that open standards can help to address problems of interoperability over time, much as they support interoperability across systems at a given point in time. Stielow (1992) argued, "Electronic preservation has a chance of success only at the place where standards exist and where we can reasonably project some constancy over time" (p. 334). In 1996, the Task Force on Archiving of Digital Information argued for the potential value of incorporating "data standards" into digital preservation strategies. Dollar (1999) presented standards and open systems as vital components of a digital preservation strategy, though he also raised warnings about the danger of adopting standards that do not ultimately win out in the market. The most outspoken critic of reliance on standards is Jeff Rothenberg, Senior Computer Scientists at the RAND Corporation. He warns that standards, like proprietary formats, will become obsolete over time. Rothenberg suggests "standards may play a minor role in a long-term solution by providing a way to keep metadata and annotations readable" (1998, p. 12).

The lowest level issues of digital preservation involve the physical medium. The bits stored on an optical or magnetic medium degrade over time and are subject to damage from environmental factors. One area in need of standardization was thus the physical storage media and storage conditions (Carneal, 1977). This is the area of digital preservation that has seen the most active standardization and consensus. Standards have been developed and adopted by the Preservation Committee of the Audio Engineering Society (AES), United Nations Educational, Scientific, and Cultural Organization (UNESCO), NIST, NBS, IEEE, American National Standards Institute (ANSI) and the ISO.

Most of the existing standards that pertain to archival collections and digital preservation have served primarily to advance work within specific streams of activities, rather than spanning multiple professions. For example, before the recent "recognition that digital preservation poses issues and challenges shared by organizations of all descriptions" and the emerging prominence of the OAIS as a common framework, work on preservation metadata by several organizations "were conducted largely in isolation, lacking any substantial degree of cross-organizational coordination" (OCLC/RLG Working Group on Preservation Metadata, 2002, p.1).

Standards for descriptive metadata of archival materials have also developed along several distinct paths, based on the boundaries between institution or document types. For example, the archival profession developed MAchine Readable Cataloging, Archives and Manuscript Collections (MARC-AMC) (Bearman, 1990; DeWitt, 1991; Martin, 1994; Roe, 1990; Smiraglia, 1990); Archives, Personal Papers and Manuscripts (APPM) (Hensen, 1989, 1993); Encoded Archival Description (EAD) (EAD Working Group, 1998; Roth, 2001); and Rules for Archival Description (RAD) (Duff, 1999) in order to develop access systems particular to their collections.

Several standards developed in the last decade are intended to facilitate the design and management of "recordkeeping systems," which ensure the authenticity of electronic records as evidence. One of the most prominent standardization efforts in this area was a metadata scheme for the Commonwealth of Australia (Acland, 2000; McKemmish, Acland and Reed, 1999; McKemmish et al, 1999). Design Criteria Standard for Electronic Records Management Software Applications (DOD 5015.2 – STD) provides a set of requirements for the design and certification of applications used to manage electronic records (Assistant Secretary of Defense, 1997). The only records management standard to have progressed through a major international standards development organization is ISO 15489 – "Information and documentation - Records management."

Social Science data archivists have also developed metadata standards catered to the specific types of data residing in their collections, often for the purpose of exchanging data among collections of the same type. The American Council of Social Science Data Archives began discussing options for "study description schemes" at its annual meeting in 1967, and this conversation eventually resulted in a recommended unified scheme (Scheuch, 2003, p. 393). Several generations of proposed conventions for data exchange (De Vries and Van der Meer, 1992; Leighton, 2002; Rasmussen, 1978) and development of codebooks have followed. The latest effort to this end is the Data Documentation Initiative (DDI). The first public version of the DDI document type definition (DTD) was published in March 2000. A standard for collections of geographic information systems (GIS) data is the Content Standard for Digital Geospatial Metadata (FGDC-STD-001-1998).

Up until the time that the OAIS development effort was initiated in 1994, space science data standardization had also followed a relatively autonomous path. The CCSDS was formed in 1982, and it then served as an active forum for the development and promulgation of numerous standards for use by space agencies. Examples of CCSDS Blue Books relevant to space science data management that preceded the OAIS development effort are Time Code Formats in 1987, Standard Formatted Data Units (SFDU) in 1988, ASCII (American Standard Code for Information Interchange) Encoded English in 1992, and Parameter Value Language (PVL) in 1992. The system for CCSDS Recommendations is explicitly built upon the assumption that individual space agencies will continue the tradition of setting their own internal standards.

Space agencies have also developed and adopted several influential standards that have emerged outside of the CCSDS process. For example, several separate efforts have attempted to address the need for device-independent data models and software for multidimensional data sets. Common Data Format (CDF) was developed in 1985 by the NSSDC; Network Common Data Form (NetCDF) was then developed at the Unidata Program Center managed by the University Corporation for Atmospheric Research in Boulder, Colorado; and the Hierarchical Data Format (HDF) was developed at National Center for Supercomputing Applications (NCSA) in 1988. Each initiative boasts a long list of private and public sector adopters. In 1993, NASA chose to adopt HDF for data in its Earth Observing System (EOS), resulting in its own flavor, known as HDF-EOS. Even with this customization of HDF, several actors within the EOS did not perceive it be appropriate to their needs and failed to adopt HDF-EOS (Duerr, et al, 2004, p.107).

1.3.4 Broadening Awareness of Digital Preservation Problems

During the 1990s, information about the problems associated with digital preservation and calls for action reached a broader audience than they had in the past. One important conveyor of this information was the Commission on Preservation and Access (CPA), which merged with the Council on Library Resources to form the Council on Library and Information Resources (CLIR) in 1997. Issues of the *Commission on Preservation and Access Newsletter* from the late 1980s indicate a focus primarily on paper and microfilm preservation, but the 1990s saw several reports related to materials stored in digital form (Lesk, 1990; Kenney and Personius, 1992; Graham, 1994; Van Bogart, 1995; Conway, 1996; Ester, 1996; Coleman and Willis, 1997; Rothenberg, 1999a, 1999b; Green, Dionne and Dennis, 1999), and CLIR has continued to actively publish on digital preservation issues since then. While CPA/CLIR publications were primarily targeted at information professionals, digital preservation messages were also starting to reach a wider popular audience. For example, in 1995, Jeff Rothenberg published an article in *Scientific American*, which laid out issues related to long-term digital preservation and discussed several potential technical strategies for addressing them, arguing that emulation might be the most viable approach.

1.4 Design of this Study

In order to explore how and why the OAIS developed effort, which took place specifically within a space data standards body, was transformed into a standard of much wider scope, I have adopted case study research design. I have explored several units of analysis: actors, events, concepts, documentary units, and changes to documentary units. My two primary sources of data have been: (1) documents related to the OAIS development effort and (2) semi-structured interviews of select individuals. I have applied qualitative data analysis, social network analysis and some descriptive statistical analysis to these data.

1.5 Significance of the Study

This case study demonstrates that standardization is not simply a process of selecting the optimal response to a pre-defined technical problem. Through the triangulation of multiple data sources and methods, I explain that the development of the OAIS was a rich and complex process, in which a diverse set of actors with various goals and motivations collectively hashed out not only what the Reference Model says, but what it means, what problems it addresses and whose interests it represents. This is an important extension to existing scholarship on standards development, which has generally emphasized either discrete decisions made by firms or consumers (whether to adopt a given standard or proprietary products); or formal SDO balloting procedures. In order to inform future standardization activities, it is important for the standards literature to explicitly and thoroughly recognize the social context in which the activities are embedded. Technical rigor and progression through the formal voluntary consensus procedures of an SDO are both important ingredients – but they are not jointly sufficient – for the success of an open standard. The standard must also be embedded in a network of actors and other resources that give the standard its meaning, legitimacy and authority. My study provides a detailed account of how such a network formed and evolved around the OAIS.

More specifically, this study provides several important lessons to inform future standards development scholarship and practice. First, I have identified three types of ISO Archiving Workshops, which suggest distinct types of events that can be important in the development and visibility of a standards effort that is intended to span several heterogeneous streams of work activity. Second, my findings about participation and input patterns highlight the various types of involvement in which actors can engage. Writing, administrative functions, formal review, commentary, and attempts at practical application can all play important roles in a successful standards development effort. Third, my analysis of social network data for both individual actors and organizational actors demonstrates the explanatory power of considering a single set of events from the perspective of both individual and organizational interests. Fourth, my analysis of documents provides several important lessons about the document development process:

the roles of definitions and figures, the interdependencies that emerge in such a complex document, and the stabilization that can make significant revisions decreasingly likely over time. Fifth, a detailed account of what specific elements of the Reference Model document were or were not ultimately accepted can inform the development of standards and architectures intended to be "implementation-independent." Sixth, findings about the reuse of existing terms and concepts demonstrate the ways in which abstractions can or cannot be generalized for purposes of providing guidance to new sets of audiences. Finally, my study of the OAIS illustrates the crucial role of timing in the development of reference models.

CHAPTER 2 - LITERATURE REVIEW

2.1 Role of Models

To build a model is to conceive of the world in a certain delimited way.

- Brian Cantwell Smith (1996, p.815)

The idea of modeling has a long tradition in such diverse fields as art, architecture, mathematics, engineering, economics, computer science, and many other natural and social sciences. It generally involves the construction of a simplified but representative version of something else. Those working with a model tend to be aware that it is not an exact copy of the thing that it is modeling, but it is hoped to reflect enough of the relevant attributes to serve some specific purpose (e.g. storage in human memory or scientific analysis of a complex problem space). A model always "deals with its subject matter *at some particular level of abstraction*, paying attention to certain details, throwing away others, grouping together similar aspects into common categories" in ways that necessarily do "a certain amount of violence to its subject matter" (Smith, 1996, p.815-816, emphasis in original). This reduction of the complexity in the environment is consistent with the insight in "rationalization" that "control can be increased not only by increasing the capability to process information but also by decreasing the amount of information to be processed" (Beniger, 1986, 15). One can model a thing or state that already exists in the world or something that does not actually exist, but could hypothetically. For purposes of design, a model can serve as a proxy for some potential location in design space. If the model seems to hold up under scrutiny, then one can decide to commit the resources to moving in that direction.

The question of which attributes are relevant enough to include in the model cannot be answered through analysis alone, because it must account for the purpose and context of the model's use. A physicist, an architect and an urban planner would develop radically different models of the same physical space, each of which could be equally appropriate. Even within their respective disciplines, however, it is rare for their specific models to be accepted by everyone. Internal debates tend to arise over the relative merits of given models. Some arguments are based on formal properties (e.g. notation, internal consistency), but many others relate to core questions of what purposes and contexts are worthy of modeling within the discipline. It is quite common for someone to criticize a model by pointing out a situation or problem that hinges on attributes that the model does not adequately reflect. It is also common, however, for the advocate of the model to respond by asserting that the situation or problem in question is not something the discipline (or at least the specific domain of the discipline carved out by the model) should spend its time trying to address.

Such a diversity of contexts and purposes is reflected in the history of modeling computer systems. The information technology literature is riddled with terms such as data modeling, data flow modeling, business process modeling, enterprise modeling, task modeling, agent-based modeling, entity-relationship (ER) modeling and object modeling. As stated above, models cannot be evaluated without adequately considering purposes and contexts for which they will be used. Two important qualities of a model of a computer system are that it be both understandable and applicable. Since practitioners will be solving a wide variety of problems, it is probably unreasonable to assume that one model can be sufficiently understandable and applicable to all of them.

2.2 Standards and Standardization

> *The esoteric concept of a standards discipline solely of interest to specialists is outdated, and must be buried.*
>
> - Henri Durand, 1981

The literature on standards and standardization offers several important sets of insights that are relevant to my study of the OAIS development process.

2.2.1 Goals and Participation in the Standards Development Process

Standards development is both a technical and a social process. The first relevant area of standards literature concerns the motivations and participation patterns of actors involved in standards development. One important insight is that different actors participating in the same standards development effort can often be engaged in the process for very different reasons. "While the stated goal of developing a viable standard may be adopted by most of the committee members, other, secondary, goals may also exist and may be in conflict." Not all goals are necessarily tied exclusively to the final outcome of a standards effort. One important goal that can be associated with participating in the process is information gathering, i.e. learning about the practices of other actors engaged in a given area of activity (Weiss, 1993, p.37; Jakobs, 2001, p.135). One author (Zuckerman, 2001) suggests that the experts in technical fields often take part in standards development meetings, sometimes simply as observers, in order to identify the latest trends in those fields. Organizational actors can also send representatives to take part in standards efforts in order to promote the reputation of those organizational actors (Jakobs, 2001, p.135). It is also important to note that, even though they are usually acting formally on behalf of their employers, individual actors can engage in standards development efforts based on their own personal interests. In a survey of participants in several standards development efforts (Spring et al, 1994), only 25% of survey respondents indicated that they participated in the standards efforts in order to advance the interests of their employers. Accounting for 67% of the motivation for participation were "personal prestige, curiosity, and the desire to positively influence future events" (p. 13). Such findings suggest that a detailed account of a standards development effort can benefit from analysis of participation at the levels of both individual and organizational actors.

The standards development literature also suggests that some actors engaged in a standards development effort may have much more influence on the process than others. Research on voting procedures suggests that the order in which decisions are made can have a strong influence on the final outcome of a group's deliberations, which would suggest that the leader(s) of a standards development effort could have considerable influence, by setting the group's agenda (Weiss, 1993, p.39). This is consistent with the idea of "path dependence" or "founder effects," in which early ideas or innovations are often preferred over those introduced later. Cowan (1992) suggests that, within standards development efforts, "a technology that appears good early in the process can, simply with that head-start, become the final standard." As I will describe later, one important factor in such path dependency can be the "closure" that often forms around established technologies.

Weiss and Sirbu's (1990) study of several standards development efforts did not find that committee leadership status had an effect on the likelihood that an actor's proposals would be accepted by the standards committee, but Weiss and Sirbu did find that the following factors were positively correlated with the adoption of a proposal made within a standards committee: size and purchasing (monopsony) power of the firms in the coalition supporting a particular proposal and extent to which the proposing actor supported their position "through written contributions." In the standard efforts that they studied, Weiss and Sirbu did not find that final outcomes were as much the result of coming to collective agreement as they were the result of simple compromise. They found that proponents of technical approaches that were adopted by the group and proponents of approaches that were not adopted had equally strong beliefs, even after the decision, that their own proposals were technically superior.

It is also important to note that the set of actors involved in a standards development effort is not necessarily inclusive of the actors who will potential benefit from the standard once it is developed. Weiss and Toyofuku (1996) report that not all firms who produced 10BaseT-compliant products took an active role in the development of the 10BaseT standard. They identify two types of "free-ridership" in standards development efforts. Type 1 occurs when an organizational actor "chooses not to participate in the standards-development process in any way and is content to wait until the standard is complete, or nearly complete" before then adopting it (p.206). Type 2 occurs when an actor "sends representatives to the committee meetings, but only for the purpose of observation and education," rather than actively contributing to the development effort (p.206). A related observation is that not all activity that contributes to the ultimate outcome of a standards effort necessarily takes place within the meetings of the formal standards group. For example, in the development of X.25 – a wide area network (WAN) protocol standard – Sirbu and Zwimpfer (1985) found that a small informal group of actors met separately and worked out a proposed approach that they then brought back to the formal standards body.

2.2.2 Standards as Socially Constructed Artifacts

Standards are socially constructed artifacts. Edwards (2004) argues that standards "embody the outcomes of negotiations that are simultaneously technical, social, and political in character" (p.827). The values and interests involved in the setting of standards are then "embedded in the specifications of technological systems" that are based upon those standards (NRC Committee to Study Global Networks and Local Values, 2001, p.23). In order to explore the socially constructed nature of standards as artifacts, it can be useful to scrutinize not only the aspects of the standards that its developers, advocates and users find exceptional, but also the aspects that they generally take for granted (Bowker and Star, 1999).

An understanding of the social construction of standards can be further informed by a wider literature on the development and social acceptance of artifacts. Standardization is a process that involves the production, modification and mobilization of social structures. Structuration theory (Giddens, 1979, 1984) provides concepts for describing how the interactions of individuals produce, reproduce and change social structures. Rather than conceiving of social structures as external forces that constrain human behavior, this perspective sees them as composed of "recurrent social practices" that serve as "rules and resources" for those who interact within the social structure.

Structuration takes place through three modalities: interpretive schemes, facilities, and norms.

> Firstly, human communication involves the use of interpretive schemes, which are stocks of knowledge that human actors draw upon in order to make sense of their own and others' actions. They thereby produce and reproduce structures of meaning which are termed structures of signification. Secondly, human agents utilize power in interaction by drawing on facilities such as the ability to allocate material and human resources; in so doing, they create, reinforce or change structures of domination. Finally, human agents sanction their actions by drawing on norms or standards of morality, and thus maintain or modify social structures of legitimation. (Walsham, 1993, p. 61)

The "duality of structure" is the insight that the same actions that serve to reinforce social structures are the ones that serve as "seeds of change." The development of the OAIS Reference Model can be characterized by a duality of structure. The interactions of individuals taking part in the OAIS development effort have acted to produce, reproduce and change structures of signification, legitimation and domination. What it means for a system to be an "archive," what it means to do digital preservation work, and what it means for a document to be a "reference model" have all been influenced by and influenced the activities of those claiming to take part in those three activities. A large body of research on information systems (IS) draws from structuration theory (Poole and DeSanctis, 2002; Orlikowski, 2000). One important insight from this work is that the introduction of new information and communication technologies can involve "significant changes to the way in which people are expected to work and interact." (Walsham, 1993, p. 52). Yates and Orlikowski (1992) use structuration theory to study genres of organizational communication, which "evolve over time in reciprocal interaction between institutionalized practices and individual human actions" (p. 299).

An important element of my study is the investigation of the structuration processes, through which the practices of actors with an interest in digital preservation collectively constructed what the genre of "reference model" would mean in this context.

2.2.3 Larger System of Standards Development Organizations

There is a substantial body of high-level writing about ICT standards development, which characterizes SDOs, their formal procedures, and the changing role of SDOs within the computer industry (Jakobs, 2000). One persistent issue is how to structure the system for standards development in a way that can attract influential actors (government agencies, corporations, technical domain experts) without becoming too closely wedded to the interests of any particular actor or set of actors. This is the "delicate balance between an independence that leads to an unused standard and a financial dependency that produces a constrained specification" (Cargill and Bolin, 2000, p.4).

A widely reported trend, since around the mid-1980s, has been that parts of the ICT industry, sometimes combined with university researchers, have moved away from the SDO process and have instead formed more ad hoc consortia in order to establish specific standards or classes of standards (Weiss and Cargill, 1992; Updegrove, 1995; Cargill, 1999). While industry consortia can often act much more quickly than SDOs in the development of standards, consortia are likely to have much less incentive than publicly funded SDOs to develop standards (including reference models) that require significant time and energy, and have little, if any immediate financial payoff (Spring and Weiss, 1994).

2.2.4 Reference Model as a Particular Type of Standard

Many of the authors cited above provide their own particular terminology for identifying different types of standards. While it is not necessary here to enumerate the many subtle differences between the authors' taxonomies of standards, there are a few distinctions directly relevant to my study. One distinction is between anticipatory and ex poste standards (Byrne and Golderb, 2002; Schumny, 2002). The former are introduced before products are developed, while the latter are codifications of characteristics reflected in existing products. Anticipatory standards development is a "future oriented and self-creating process of defining standards: writing for the future now" (Bonino and Spring, 1999, p.101). Although its development has benefited from knowledge based on existing practice, the OAIS is largely framed as an anticipatory standard, offering concepts and terminology to drive future work in the area of digital archives.

A reference model is one important type of anticipatory standard. Whereas many of the types of models described in the previous section (e.g. data models, entity-relationship models) are designed in order to facilitate the development and maintenance of specific systems, reference models tend to be standards used at a higher level of abstraction. A representative example of a disclaimer for a reference model indicates that it "does not specify services and protocols" and it "is neither an implementation specification for systems, nor a basis for appraising the conformance of implementations" (ISO/IEC TR 10032:2003). The final version of the OAIS provides the following definition of reference model:

> A framework for understanding significant relationships among the entities of some environment, and for the development of consistent standards or specifications supporting that environment. A reference model is based on a small number of unifying concepts and may be used

> as a basis for education and explaining standards to a non-specialist (p. 1-11).

The above definition is not the only way to conceive of reference models. In fact, this definition contains substantive changes from the one first proposed (Reich and Sawyer, 1995) for use in the OAIS development effort.

I have identified twenty-two distinct, though often inter-related, purposes or characteristics of reference models:

1. Provides a high-level set of principles and concepts
2. Context within which standardization will occur
3. Means for identifying what standards are necessary
4. Basis for comparing standards
5. Means for identifying relationships between standards
6. To verify and refine requirements
7. Means to identify needed interfaces
8. To specify interfaces
9. To develop models
10. To define an architecture
11. Identify characteristics that qualify systems as X (can support conformance testing)
12. Assessment and evaluation
13. Identify or describe processes, functions, services, activities or events in a particular domain
14. Provide common language, terminology and concepts
15. Support modular research, development and standardization
16. Serve as a boundary object between user groups
17. Means to unambiguously specify or reference system attributes or data values
18. Support interoperability, including as a means to map or transform values across frames of reference
19. Basis for new concepts and contributions
20. Support analysis and comparison of systems
21. Independent of specific implementations
22. Theoretical model for explanation and prediction[10]

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[10] Some authors have applied the label "reference model" to their theoretical work in a way that diverges markedly from the way this term is used in a standards development context. For example, Turski (1996, 2002) presents a model for the growth of software systems. The product of this work is a formal equation, rather than a framework or set of concepts.

The above list is based on an analysis of two general areas of literature: (1) literature that discusses the nature of reference models in general (Averill, 1994; Bonino and Spring, 1991; Dollar, 1992, p.88; Oberndorf and Earl, 1998; Shaiman, 1995; Spring and Weiss, 1994; Tang and Scoggins, 1992; Tolk, 2003; Tolk and Muguira, 2003), and (2) documents that claim to be reference models, which often indicate what they take to be the role and purpose of the document (Gupta, 2003; ISO/IEC TR 10032:2003; ISO/IEC CD 18026; Padlipsky, 1982; Spring, 1996; Turski, 1996, 2002; Zimmerman, 1980). A large portion of this literature stems from efforts within the public sector. The most notable actors in the development of reference models over the past three decades have been the ISO, European Computer Manufacturers Association (ECMA), NIST, and components of the U.S. Department of Defense (DOD).

One primary area in which authors differ is the appropriate degree of specificity or granularity of reference models, i.e. the weight and interpretation of the requirement that a reference model should be application- or implementation-independent (#21 above). For example, according to one source, a reference model "identifies interfaces which may be the subject of future standardization" (ISO/IEC TR 10032:2003) (#7 above), whereas other sources indicate that a reference model specifies the details of those interfaces (#8 above). A reference model is sometimes claimed to provide an "architecture that will allow the development of multiple applications" (Gupta, 2003, p.936) (#10 above), but other sources insist that an architecture requires much more detailed technical specification than a reference model.

Despite these differences, there is a general consensus that reference models exist at a higher level of abstraction than other standards. One of the most prominent authors on this topic is Carl Cargill (1989, 1997). He provides a framework for describing standards, which distinguishes providers of information technology products and services from the users of those products and services (see Figure 2 below). According to Cargill, it is a mistake to analyze these two groups together, because they have very different motivations and needs in the standardization process.

> On the provider side is the global model that describes all of the potentials that the IT industry will need to satisfy all users over a long time in nearly all situations, and that serves as a reference for all providers. This reference model, if it is correctly constructed, includes some present and future technologies, a road map function, and some of the methodologies of the thought processes that occurred when it was constructed. The time span covered is up to ten years, and the model is applicable to all technical disciplines that deal in this area. On the IT user side is a description of a solution implementation that is immediate and particular to that user's application problems. Both providers and users have something that they call standards; the definitional gap is tremendous (1997, p. 90).

Cargill explains that bridging the gap between reference models and application implementations requires a chain of standards at increasing levels of specificity. The first link in this chain is an industry consensus standard, which describes a subset of the functions or capabilities identified in the reference model. In other words, it is an “implementation of the strategy contained in the reference model” (p. 90). Second, a functional profile then describes a set of functions from the industry standard for a specific, but large, class of users. The functional profile sits at the intersection between providers and users, translating “the potentiality of an industry's capabilities in a certain area into a set of functions from which the users can begin to construct a more specific system” (p. 91). The third category of standard is the systems profile, which describes the system requirements of a smaller group of users than that addressed by the functional profile. Finally, a specific organization has its own needs and requirements, which are often addressed by a document or set of documents that specify the implementation in this particular organizational and technical context.

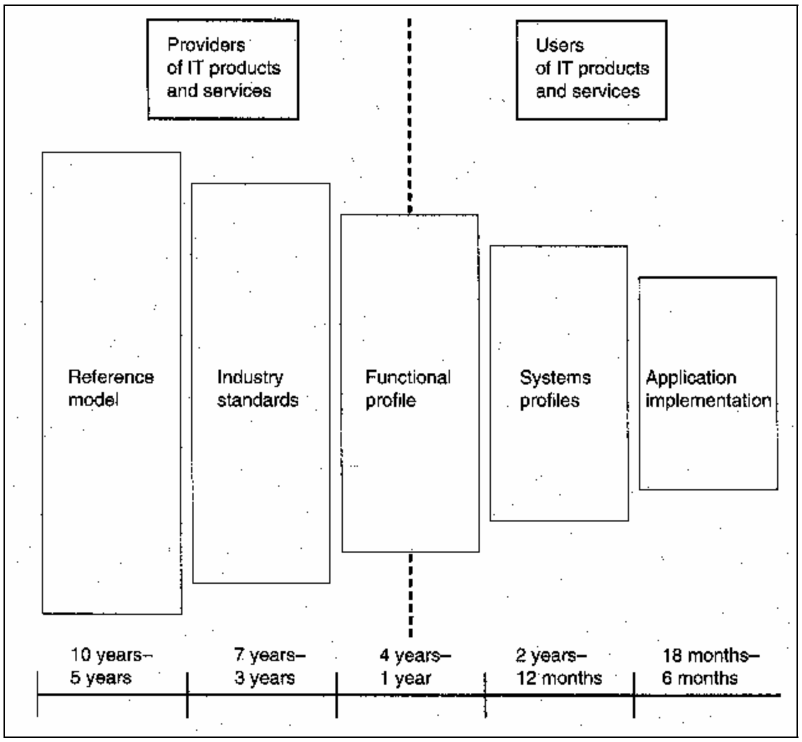

Figure 2 - User-Provider Standardization Planning Model
[Source: Cargill, 1997, p. 92]

Another way to conceive of the role of the various categories of standards presented in Figure 2 is in terms of the degree of interoperability or tightness of coupling that is ensured by building systems that comply with a given standard. Tolk and Muguira (2003) propose a model based on five levels "conceptual interoperability": Level 0 - System Specific Data; Level 1 – Documented Data; Level 2 – Aligned Static; Level 3 - Aligned Dynamic; Level 4 – Harmonized Data. The "use of common reference models/common ontology" is included in Level 2. Levels 3 and 4 are necessary to ensure full conceptual interoperability.

As the most generalizable – and thus potentially persistent – form of standards, reference models can serve as important resources in the structuration processes of an industry or field. As I described earlier, structuration is characterized by a duality of structure. The resources upon which actors draw in order to create social structures are the same resources that actors draw upon to reinforce and modify those structures. Cargill's predictions about the future role of reference models reflect this duality of structure. He says that they will not only act as "the premier planning devices for the industry" but they will also "become the change agents for the way that IT evolves." If actors do rely on relatively stable reference models for high-level planning and strategizing, then this reduces the chances of immediate and radical changes, or what Cargill calls "revolution" (p. 92). However, their characteristics as abstractions – sufficient generality to free them from the content of specific implementation contexts, and sufficient formality to support legitimacy and applicability in addressing professional problems – also allow reference models to be resources that actors can potentially mobilize to bring about significant technological and institutional change.

2.2.5 Standardization in the Structuration of Work Activities

Standardization can help to set the direction of product development within an industry, but it can also contribute to the signification, legitimation and enforcement of notions about how work should be done within a particular stream of activity. For example, the development of formal management hierarchies and the systematic management movement in the 19th-century United States were based on an intersection between standardized metrics, tools and resources; and the differentiated professional status of managers and engineers who had the expertise to control and coordinate the use of such metrics, tools and resources (Cargill, 1989, p.21; Yates, 1989; Zuboff, 1988; Chandler, 1980, p.12, 34).

Standardization and the structuration of work activities can intersect whenever the elements of work are formally defined. One such area of activity is “standardization of job descriptions or methods of generating job descriptions across firms” (Smith, 1984). Several authors have investigated this relationship within the archival profession, specifically discussing the ways in which the development of the MARC AMC cataloging standard impacted employment practices (Dewitt, 1991; Cox, 1994). Standardization is also involved in the development of protocols, i.e. detailed sets of instructions for carrying out a particular type of work. Questions related to the role and potential dangers of protocols within the medical professions have gained prominence in recent years (Berg, 1997).

Standards can serve to explicate and codify particular aspects of work activity. Davis (2003) explains the role of descriptive standards in “the codification of archival knowledge and the development of the profession’s first standards of practice” (p. 292). Bowker and Star (1999) discuss the role of Nursing Intervention Classification (NIC) in the definition of nursing work. Such standardization can legitimize areas of work that were previously invisible to high-level decision makers, but they can also open up that same work to additional control.

> The essence of this politics is walking the tightrope between increased visibility and increased surveillance; between overspecifying what [the worker targeted by the standardized description] *should* do and taking away discretion from the individual practitioner" (p. 29, emphasis in original).

The case of NIC also demonstrates that the creation and control of abstractions through standardization is often not under the exclusive control of the one group of individuals whose work is being described by those abstractions (in this case, nurses). Abbott explains that it can be a mixed blessing for an area of work activity to be characterized by a very clear and transparent alignment between the classification used for diagnosis of problems and the classification used for treatment of problems. "On the one hand, identifying the two would clarify and simplify professional work, at the same time making it more comprehensible to outsiders. Yet it would also make professional work more easily downgraded" (p. 45). A similar tension exists in relation to standardized metrics of work. If results are not measurable, there is "less need to prefer one treatment to another, and thus a weaker professional hold on the problem area," but "results that are too easily measurable lead to easy evaluation from outside the profession and consequent loss of control." Standardized metrics can also allow competitors to demonstrate their superiority in the treatment of problems (p. 46).

Standards development organizations and coalitions – such as the CCSDS responsible for the OAIS – are missing from Abbott's account. He does not explicitly address the important role of such groups in the dynamics of defining areas of work activity, nor generally does the literature on standards development. For example, Cargill (1989) contends:

> the consensus standards process helps the market determine when innovation is frivolous and when it serves a purpose, by providing a **neutral arena** where the impacted community as a whole **safely** can question, advocate, argue, and generally explore an innovative approach (p. 37, emphasis added).

While such claims of neutrality and safety might be justified within the context of a market or industry as a space of innovation, they are not justified within the context of an arena of competing claims over work activities.

Professional associations and standards development organizations have the potential to serve as agents of change in arenas of work. For example, in the 1920s and 1930s, museum professionals were able to "function as conservatives in organizational roles at the same time they used fieldwide organizations" to bring about changes in the way their work was structured and defined (DiMaggio, 1991, p.268). Thompson (1954) also provides an account of how the Society of Automotive Engineers (SAE) took on the role of setting standards for an entire industry. Thompson explains that Howard E. Coffin became president of the SAE in 1910, which was a time characterized by a brief "economic crisis" in the auto industry and "a body of professional automobile engineers, without trade association entanglements, [who] stood ready to help create intercompany standards." (p.4) Coffin and other actors were able to enroll the existing SAE to take on the role of standards bearer when there was a vacancy for such activities in the environment, which resulted in a dramatic transformation of the industry.

2.3 Abstractions and Boundary Spanning

According to the Oxford English Dictionary, abstraction is the process or product of "separating in thought, of considering a thing independently of its associations; or a substance independently of its attributes; or an attribute or quality independently of the substance to which it belongs." Abstraction is an essential component of the creation of models, as described in 2.1 above. Abbott (1988) distinguishes two aspects of abstraction: (1) "lack of content; that is abstract which refers to many subjects interchangeably” and (2) “positive formalism, which may in fact be focused on a fairly limited subject area” (p.102). The development of a reference model attempts to capture both of Abbott’s aspects of abstraction, within a single unified document. Abbott’s two aspects are also the same combination of factors that can make for a good boundary object. The first sense of abstraction supports generalization across social and technical contexts, and it also promotes longevity (use across temporal contexts); while the second sense supports the ability to apply the reference model in specific contexts. Positive formalism also lends legitimacy, significance and normative weight to an abstraction, i.e. it contributes to the structuration of one or more social systems. While ICT standards are generally characterized by positive formalism, it is Abbott’s first aspect of abstraction that sets reference models apart from other types of standards.

The existing literature on standardization is also generally silent on the role and value of heterogeneous viewpoints and ambiguous wording of standards. Lack of precision in a standard is generally characterized as a negative side effect of conflicting interests or market forces, rather than a positive sign of collaborative sensemaking. This may be the result of focusing on a completed standard as a fixed entity to be diffused and adopted, rather than considering it as a boundary object. One area of standards literature that does hint at these issues is the literature that discusses reference models. Such discussions generally recognize the value of reference models being more general and (though the authors usually do not use this term) vague, in order to remain relevant in an environment of rapidly changing technologies, systems, architectures, and lower-level standards.

Because potential members will generally be affiliated with one or more established organizational actors and streams of activity, new abstractions must also serve as boundary objects (Star and Griesemer, 1989; Bowker and Star, 1999), spanning existing boundaries, in order to attract, mobilize and motivate new members. Boundary objects can take the form of artifacts but also concepts and actors. Formal standards, such as classification systems can play this role (Albrechtsen and Jacob, 1998). Abstractions have the potential to promote the learning, meaning and identity relations of one or more communities of practice associated with a nascent area of work (Lave, 1991; Wenger, 1998; Wenger, McDermott and Snyder, 2002). Actors from the surrounding environment can also can also themselves serve as boundary objects between the environment a community of practice by engaging in “legitimate peripheral participation” in the activities of that community.

A set of abstractions will best support cooperative activities if it is adaptable (Simone and Sarini, 2001) and attends to the particular information needs of "boundary work" (Palmer, 1996). While some degree of formality and specificity is important, there is also value at both individual (Allison and Eylon, 2003) and institutional levels (Grundfest and Pritchard, 2002; Nakamura and Smallwood, 1980) in retaining some ambiguity in the abstractions that are intended to guide future strategies and behaviors. Rather than attempting to optimize for one specific context, an abstraction can benefit from "robust action" (Leifer, 1991; Padgett and Ansell, 1993) or "robust design" (Hargadon and Douglas, 2001), which is effective in the short-term but also sufficiently flexible to remain effective in a wide range of possible future contexts.

2.4 Knowledge Transfer, Enrollment and Reuse

The development of a reference model can benefit from the drawing together of many pre-existing elements of the surrounding environment. Lessig (2004) explains how even the most creative acts involve elements of reuse. Other authors have emphasized the value of innovations that combine and recombine existing artifacts and social structures (Schumpeter, 1934; Nelson & Winter, 1982; Hughes, 1983). Such activities are not a simple matter of mindless copying, but instead require the actors involved to attend to various barriers and facilitators to the reuse of artifacts, concepts and actors from the environment (e.g. Argote, 1999; Argote, et al, 2000; Argote, Beckman and Epple, 1990; Szulanski, 1996, 2000).

In order for an element of the environment to be taken up as part of a new development effort, it must have meaning and value to the actors engaged in the development effort. The process of gaining new adherents is the focus of a substantial body of literature on the diffusion of innovations. According to Rogers (1995), diffusion is a special category of communication, "concerned with the spread of messages that are perceived as new ideas." An innovation can be an "idea, practice, or object." Its defining characteristic is its perceived newness to the target entity (what Rogers generally refers to as "an individual or other unit of adoption").

Rogers presents several characteristics of innovations to help explain their rates of adoption (p. 15-16): relative advantage, compatibility, complexity, triability, and observability. Another prominent body of research has built and elaborated upon the technology acceptance model (TAM) (Davis, 1989; Davis, Bagozzi and Warshaw, 1989), which aims to predict and explain an innovation's acceptance based on perceived usefulness, perceived ease of use and consistency with social norms[11] (Adams, Nelson and Todd, 1992; Taylor and Todd, 1995; Venkatesh and Davis, 1996; Jackson, Chow and Leitch, 1997; Agarwal, 1999; Al-Gahtani and King, 1999; Malhotra and Galletta, 1999; Venkatesh and Davis, 2000; Venkatesh, 2000; Kivimaki and Fomin, 2001; Chau and Hu, 2002). While most of this research focuses on the adoption and use of office information technology such as software, it explores factors that are potentially relevant to the acceptance of more text-based technologies, such as standards documents, concepts and models.

Rogers gives relatively little attention to those characteristics of an innovation that can support multiple interpretations, conceptions and purposes. This is also true of literature inspired by the technology acceptance model. Both of these research traditions tend to treat a given technology/innovation as a discrete entity to be diffused, adopted or rejected based on how a given social entity (individual or group) perceives and interacts with pre-existing characteristics of the technology/innovation. For Rogers, "re-invention" is the process of transforming an innovation – i.e. creating of a new innovation – based on the needs of a new context. Although he acknowledges that this is a widespread phenomenon, Rogers describes it as something that occurs after the properties of the initial innovation are effectively fixed and stabilized. Such a theoretical approach fails to address the "interpretive flexibility" of technologies that have not yet reached the point of "closure" (Pinch and Bijker, 1984). In order to understand the development of a high-level, largely anticipatory standard, such as the OAIS, it is important to attend to

[11] The third factor, social norms, is part of the original TAM but has received much less attention in the literature than the first two.

both the elements of interpretive flexibility and the elements of closure involved in the Reference Model's construction.

2.5 Conclusion

In this chapter, I have reviewed the literature on models, standardization, abstractions as tools for defining work, and the reuse/enrollment of elements of the environment in development activities. The fruitful intersections between these literatures that inform my study relate to the processes through which actors collectively construct the abstractions that formally define types of work. The literatures on diffusion of innovations and structuration theory together provide a valuable conceptual framework for describing and explaining the social processes of developing a high-level standard such as a reference model. Research on boundary objects contributes an understanding of how a reference model (as a set of abstractions) can be designed to support work in local contexts while also supporting coordination and communication across the boundaries of established streams of work activity.

My discussion of digital preservation indicates that this is an area of work activity that has been emerging for several decades, through the distinct and largely uncoordinated efforts of actors within many existing streams of activity. Each stream has come to recognize elements of this work as distinct and legitimate, but the elements have usually not been considered part of the core of any existing professions, institutions or disciplines. During the mid- to late-1990s, actors involved in the separate streams of activity increasingly began to recognize that there were many place where the streams intersected. The development of the OAIS, from 1995 to 2002, took place within this context.

CHAPTER 3 - RESEARCH DESIGN AND METHODS

Development of the OAIS is unusual for two important reasons. First, it has gained prominence and acceptance among a diverse set of actors. Second, it has done so despite being developed within a standards development organization whose formal mission and previous standards products did not address such a diverse set of actors, but was instead focused specifically on the needs of space science agencies and their contractors. This study is concerned with the following question:

> *How and why was the OAIS development effort, which took place specifically within a space data standards body, transformed into a standard of much wider scope?*

In order to address the request question above, I have conducted a case study of the OAIS development process. The case study is a type of research design, rather than a specific method for data collection or analysis. It is a useful research design "in examining contemporary events, but when the relevant behaviors cannot be manipulated" (Yin, 1994, p. 8). A case study focuses on a bounded set of phenomena associated with a specific event, process, or activity, which is not the same as focusing on a single data point. By adopting methods that involve many different observations of the phenomena under investigation, a researcher can make valid inferences from a single case study (King, et al, 1994). I have supported my findings through the triangulation of several research methods (Jick, 1979).

When constructing a case study, it is important to identify the boundaries of the case in order to "stay within feasible limits" (Yin, 1994, p. 22). Focusing one's research on a limited set of events, activities and actors "is the equivalent of the archaeologist measuring to a fraction of an inch the length and breadth of his trench. Restriction defines the task" (Clanchy, 1993, p.20). The scope of this case study is the set of activities surrounding the formal OAIS development process, which began on April 15, 1994, with a New Work Item proposal and ended on February 24, 2003, when the ISO published the OAIS as an International Standard.

3.1 Units of Analysis

This case study involves several units of analysis: actors, events, concepts, documentary artifacts, and changes to documentary artifacts. Actors are entities to whom I attribute agency in the OAIS development process. They can be either individuals or organizational actors. Events are the ISO Archiving Workshops in which actors engaged. The concepts are those included in one or more versions of the Reference Model. Documentary artifacts are units of textual or graphical material enrolled in the OAIS development effort. This includes complete documents, shorter strings of text, and figures. Changes to documentary artifacts are those involved in the development and revision of the Reference Model. They include addition, removal and revision of both textual and graphical representation of ideas.

3.2 Data Sources

In this research project, I have used two primary sources of data: (1) documentary sources, and (2) participants in semi-structured interviews.

3.2.1 Documentary Sources

3.2.1.1 Records from the OAIS Development Process

The primary source of data for this study is the documentation associated with the series of meetings called ISO Archiving Workshops. There were 36 such events between October 11, 1995 and October 24, 2001: 18 US workshops; 13 international workshops; one French workshop; two UK workshops (the second called "Digital Curation")[12]; Digital Archive Directions (DADs) Workshop; and Archival Workshop on Ingest, Identification, and Certification Standards (AWIICS). Documentation from these meetings provides the following general types of data:

- Content of meeting discussions – Documents include meeting minutes, meeting reports and presentations made at ISO Archiving Workshops.
- Reports and white papers developed in order to address specific issues raised during the OAIS development effort.
- Public comments in the formal of formal Review Item Disposition (RID) documents and less formal written submissions.
- Drafts of the reference model.
- Participation data - For all 36 Workshops, I have been able to obtain information about attendees either through the CCSDS or other actors responsible for the event, in one or more of the following forms: list of participants, list of those present in workshop minutes, or names of responsible individuals next to items on workshop agendas. An inventory of all listed participants in these events reveals 306 distinct individuals. I have used these data to identify potential interview participants and analyze participation trends throughout the process. The data generally indicate participants' institutional affiliations but not their professional affiliations and usually not their specific job titles.

3.2.1.2 English-Language Literature Discussing the Reference Model

I have compiled a collection of 335 English-language documents – reports, conference papers, articles, and books – from 1995 to April 2005, which cite or discuss

[12] The ISO Archiving web site does not list Digital Curation as one of the ISO Archiving Workshops, but I have included it in my analysis because of the stated OAIS-related objectives of the event and the involvement of several members of the OAIS core leadership.

the OAIS (see Appendix 3 – English-Language Literature Citing or Discussing the OAIS). These citations are based on monitoring of the digital preservation literature over the past several years and conducting searches[13] for OAIS literature in the search utilities for several particular serial publications[14] and professional organizations,[15] as well as more general scholarly databases[16] and the Web even more broadly (using Google). The resulting corpus of documents allowed me to identify patterns in the dates, sources and general focus of external literature citing or discussing the OAIS. This was important to my study, because many of the external documents, and the actors involved in their creation, played a part in the OAIS development process. Further development and analysis of this list of literature could also be a promising component of future research on the adoption and diffusion of the OAIS.

3.2.2 Semi-Structured Interviews of Workshop Participants

I used interviews to generate a richer understanding of the issues addressed in the survey. Interviews allowed me to delve into the details of personal attitudes, perceptions and motivations. This data collection method is useful when a researcher wishes to study participants' past activities and cannot directly observe the actors engaging in those activities (Creswell, 1994; Taylor and Bogdan, 1998; Weiss, 1995).

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[13] Queries varied depending on the characteristics of the sources, scope of collection coverage and search interface involved. In the majority of cases, I used the simple query "OAIS," but in other cases I also used the phrase "Reference Model for an Open Archival Information System" and sometimes the shorter phrases "Open Archival Information" and "CCSDS." Collecting relevant sources involved manually filtering out many false positives based on phrases such as "Opinion, Attitude and Interest Survey," "Office of Administrative Information Systems," "Or-And Inverters," "off-axis illuminations," and (especially) the software package known as "OAISter."
[14] *Ariadne*, *D-Lib Magazine*, *First Monday*, *Journal of the American Society for Information Science and Technology (JASIST)* (through Wiley InterScience), *RLG DigiNews.*
[15] ACM Digital Library, IEEE Xplore, CLIR, ICSTI Forum.
[16] CiteSeer, Google Scholar, Inspec, Wiley InterScience, Wilson Index to Journal Articles

I carried out 21 semi-structured interviews of a stratified sample of individuals who took part in the ISO Archiving Workshops. I conducted most interviews by phone, though I conduct five of them in person. I created audio recordings of each interview and arranged for them to be transcribed, except for two cases in which interview participants did not agree to be audio recorded. For those two interviews, I took details during the interviews and used those notes for coding and analysis. I used anonymous identification numbers for each audio file, in order to protect the confidentiality of the participants. For some individuals who consented to doing so, I also engaged in follow-up correspondence through email, in order to clarify or elaborate on the information they provided in the interviews. I stored this email on a secure server, protected by a password. For purposes of analysis, I removed personal names and associated anonymous identifiers with the messages.

In advance of the interviews, I sent participants both a summary of the interview questions and the documents (or pointers to those documents on the Web, when available) generated from the OAIS development meeting(s) in which they took part,[17] in order to give them the opportunity to jog their memories before engaging in the interviews.

3.2.2.1 Interview Topics

Issues addressed in the interviews are the following (see Appendix 4 - Interview Instrument and Appendix 5 – Interview Background Information Form):

- Professional affiliation

[17] I did not send Workshop documents or pointers to Workshop documents to the 12 participants who fell into sampling category 1 (see section 3.2.2.2), because they all attended many Workshops and knew how to find the related documentation if they chose to do so.

- Institutional reasons and resources for participation in the OAIS development process (i.e. who paid for it and why)
- Personal reasons for involvement in the OAIS development process (why he/she thought it was important and what he/she hoped to get out of it)
- Skills and expertise participants felt they brought to the process
- Types of skill and expertise he/she felt other participants brought to the process
- Perceived relevance of taking part in the OAIS development process to (1) his/her job and (2) advancement of the goals of his/her profession
- Closure vs. openness of particular aspects of the reference model (i.e. which aspects were discussed as open for negotiation and which seemed to be taken as given and fixed)
- In the discussion of the OAIS at the workshop(s) in which he/she took part, some striking examples of terms or concepts that were (1) borrowed from somewhere else and (2) invented specifically for the standard
- Perceived relevance of the OAIS final document (Blue Book) to (1) his/her job and (2) advancement of the goals of his/her profession

3.2.2.2 Interview Participant Sampling

My research design called for 21 interviews, based on a set of four sampling categories. The fundamental rationale for my sampling approach is that those with different levels of involvement are likely to have different reasons for participating, forms of involvement and perspectives on the standards development effort. The four categories were the following:

1. **Consistent workshop participants** (total = 14, interviewed = 12)

I attempted to interview everyone who took part in 10 or more Workshops. All of these individuals were actively involved through all or most of the process (spanning Stages 2-4 or longer).

2. **Participants who predicted "core" membership** (total = 6, interviewed = 3)

In the minutes of the First US Workshop (October 11-12, 1995), seven individuals said they expected to serve as the "core group," meaning they would devote 10% or more of their time, generate new material and attend future Workshops. One of these individuals did, in fact, take part in enough workshops to place him in category 1 above.

All of the other individuals in this group actually attended four or fewer Workshops. I attempted to contact all individuals in this category.

3. **Active participants who entered the process late or left early** (total = 11, interviewed = 2)

This category is defined as those participating in 4-9 Workshops (excluding two individuals who fall into category 2 above) and who either entered the process late (Third International Workshop on November 4-5, 1996 or later, i.e. after Stages 1-2) or left the process early (before the Eighth International Workshop on May 1999, i.e. before Stage 4). I attempted to contact all of the individuals in this category.

4. **One-time participants** (total = 243, interviewed = 4)

This was a provisional sampling category of individuals who attended only one Workshop (and did not fall into category 2 above). If I had not secured 21 interviews in the three categories above, I planned to contact individuals who took part in only one workshop. Sampling within this category was purposeful rather than random. First, I attempted to arrange for interviews with one-time participants who were mentioned by participants in earlier interviews. Second, I contacted individuals whose presence or absence received considerable attention in the Workshop documents. In both cases, the individuals' roles in the OAIS development effort were important, even though they were acting as relative "outsiders" to the process. I worked through the list of one-time participants until I had a total of 21 interviews. I attempted to contact seven individuals in this category and received responses from six, four of whom agreed to be interviewed.

3.3 Data Analysis

I have applied a combination of qualitative and quantitative analysis methods to the data described above.

3.3.1 Coding and Analysis of Work Documents

One of my primary methods has been emergent qualitative coding and analysis (Dey, 1993) of documents. I coded for the following: origins of terms and concepts introduced into the Reference Model; chronology of further elaboration, revision or removal of those terms and concepts from the Reference Model; discussions and decisions related to Reference Model changes; roles and contributions of particular actors; objectives and motivations of actors for participating; discussions of the intended scope and purpose of the Reference Model; work process, including action items and deadlines.

Coding and analysis of documents was a very iterative process. I began with “in-vivo” coding, meaning that codes were based on selection of phrases as they appeared in the original documents. Categories of codes began to emerge from this initial coding. As I coded based on those initial categories, I made additional refinements based on the findings of my coding along the way. For example, the coding of new concepts often resulted in a chaining back to earlier documents in the OAIS development process or related external documents, in order to identify the earlier origins or motivations for later introducing the concepts. My grouping of findings into three high-level categories – Work Structure and Process; Participation and Input; and Contents of the Reference Model – came after I had completed my preliminary round of document analysis based on the entire corpus of OAIS development documents. These three categories have supported additional rounds of data reduction, synthesis and analysis.

3.3.2 Coding and Analysis of Versions of the Reference Model

I have applied a detailed set of codes to all 20 versions of the Reference Model. I have identified the terms defined in each version of the Reference Model; whether each term is new, revised or has been dropped between versions; and notes associated with changes made to the definition. I have also identified figures included in each version; whether each figure is new, revised or has been dropped between versions; and notes associated with changes made to the figure (see Appendix 7 for a graphical representation of this analysis in relation to the functional model of the Reference Model). I have also coded for presence and changes within each version of the Reference Model of important concepts and issues within the body of the text that are not necessarily reflected in definitions or figures, as well as higher-level structural changes such as addition, removal or moving of sections within the document. From the codes I applied to the versions of the Reference Model, I have generated both qualitative findings and descriptive statistics related to the contents and revision of the Reference Model, many of which are presented in Chapters 4 and 5.

3.3.3 Social Network Analysis

Within the social sciences, there is a long tradition of research on social structure. One approach to such research that has gained prominence relatively recently is structural analysis or social network analysis (Wellman and Berkowitz, 1988; Padgett and Ansell, 1993; Scott, 2000; Wasserman and Faust, 1994). Rather than collecting data on the attributes of a sample of individuals and then inferring their structural relationships based on correlations between those attributes, structural analysis treats the relationships themselves as the fundamental unit of analysis. Within the context of my study, this approach has allowed me to investigate characteristics of the affiliations (to each other through attendance of meetings) of participants in the OAIS development process.

I have conducted social network analysis at two levels: individual actors and organizational actors. The analysis of individual actor relationships is based on an affiliation matrix (Wasserman and Faust, 1994) derived from the records described in 3.2.1. The rows of this matrix are the 306 individual actors listed as participants of at least one Workshop related to OAIS, and the columns are the 36 ISO Archiving Workshops that fall within the scope of my study.

Analysis of organizational actor relationships is also based on an affiliation matrix derived from meeting participation lists. The columns are again the 36 Workshops, but the rows are the names of organizations with which individuals indicated they were affiliated in the participation data for each Workshop.[18] In many cases, individuals indicated different organizational affiliations at different meetings,[19] and these self-reported data are reflected in the matrix, i.e. I have used the organizational affiliation identified in the participant list for each specific Workshop. The rationale for this approach is that, even if the person might be otherwise associated with another

[18] When available, affiliation data is from registered participants lists rather than meeting minutes (registration data usually includes more detailed affiliations).
[19] This is occasionally due to an individual switching jobs or a merger of her employer with another entity. More often, however, these differences in reporting of affiliations are based on decisions about which of multiple professional roles to express in a given venue.

organization in other Workshops, this indicates the organization he/she deemed him/herself to be representing at this particular event.

An important and difficult set of issues involved in coding data at the organizational actor level relate to complex organizational structures. Individuals often work for offices, divisions, departments, units or agencies that are embedded in even larger organizational structures. A further complication is that organizational structures are not always strict hierarchies; there can be one-to-one, one-to-many, and many-to-many relationships. The relationships can also take a variety of forms. For example, the JPL is managed by the California Institute of Technology, but it is also a federally funded research and development center (FFRDC), which has a long-standing arrangement to conduct work for NASA; several research centers and laboratories are formally located within universities or government agencies but operate relatively autonomously and involve numerous partners located outside their host organizations; some organizational actors in Europe report in different ways to both the European Union (EU) and the countries in which they are located. In order to address these issues, I have again relied on individual self-reports, as reflected in the Workshop participation lists. If, for example, an individual listed his/her affiliation at a particular Workshop as GSFC, which is a unit within NASA, I have identified the organizational actor to be GSFC, rather than NASA.

When an individual listed more than one organization in a given Workshop (e.g. “GSFC / CSC”), both organizations have “1” added to the cell associated with that Workshop. This means that, within the organizational actor relationship matrix, an individual actor’s participation will be registered more than once for particular

Workshop, in order to reflect that this individual actor was serving to represent more than one organizational actor at the Workshop. An important exception is that when the participant indicated two affiliations that are subsets of one another hierarchically (e.g. “NASA GSFC”), only the most specific of the affiliations is used.

3.3.4 Qualitative Coding and Analysis of Interview Data

Coding and analysis of interview data was also an iterative process. I used QSR’s NVIVO software to code and analyze transcripts of the interviews. I made use of two broad categories of codes within NVIVO: tree nodes and free nodes. Tree nodes are arrangement within a hierarchical structure. Free nodes are not arranged within a hierarchy and are useful for concepts that fall in between or cut across existing tree node categories. The questions in my two interview instruments (see Appendices 3 and 4) provided one initial set of coding categories and sub-categories (tree nodes). However, two factors necessitated the creation of additional coding categories. First, the interviews were semi-structured, allowing participants to discuss issues that were not responses to specific questions in my instruments. Second, many themes emerged from the data which I had not explicitly built into the instruments. Each time I encountered a statement or set of statements in an interview transcript that was relevant to my research question but did not fall into any existing codes, I created a new code. As I progressed through the coding of transcripts, the rate at which I created new codes (as opposed to applying existing codes) decreased. As analysis continued, I moved some of the free nodes into new or existing categories (tree nodes), but some remained free nodes to the end, thus serving as their own categories for analysis. The final result of this coding was a set of 115 tree nodes and 63 free nodes. In developing the findings for my study, I generally based the findings on codes that I had applied to many different transcripts. I usually do not report on codes that I applied to only one or two instances of transcript text, unless those codes are also supported by a substantial body of evidence from the document or social network data.

3.4 Limitations

Each of the three main research methods I have adopted for this study – document analysis, social network analysis, and analysis of interview data – presents distinct challenges and limitations.

3.4.1 Document Analysis

Documentary sources, such as meeting minutes and research reports, provide a filtered version of the processes upon which they report. First, there are gaps in the documentary record. All of the 36 ISO Archiving Workshops that fall within the scope of my study have some publicly available[20] associated documents, but their level of detail varies considerably from one Workshop to another. For example, of the 36 Workshops, 14 do not have associated meeting minutes. The Workshops without minutes – many of which took place late in the OAIS development process – still generally have several other very informative documents, such as agendas, action items, presentations, participant lists and documents for review. However, without a document summarizing

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[20] My primary source of documents was the ISO Archiving web site, which provides individual sections for almost all of the ISO Archiving Workshops. John Garrett at GSFC provided me assistance in locating many documents that had moved to different servers. I was also able to discover and then analyze numerous documents that are now hosted by the Rutherford Appleton Laboratory (RAL) at http://www.ssd.rl.ac.uk/ccsdsp2/. Although there are very few documents on the web site associated with the French Workshop, Claude Huc was kind enough to send me a physical copy of a sizable package that includes the Workshop's documents.

the conversations that took place, it can be difficult to determine exactly what issues received the most attention, how particular ideas were received by the group and how decisions were made. Conversely, it is often easier to get a more detailed account of specific changes to the Reference Model that occurred during the later stages in the development process than it is for changes that occurred with the early versions of the Reference Model. This is because later changes often took the form of formally submitted comments, responses, and written agreement on every provision. The early process, on the other hand, involved dramatic changes between versions of the Reference Model and often less direct documentary evidence about specific textual revisions.

A second issue with meeting documents is that, even when the Workshops are well-documented, there are various events and activities that took place in between Workshops. Conversations took place through teleconferences, email and face-to-face conversations outside the Workshops. As I will discuss in Chapter 5, based on interview data, a small set of core Reference Model editors often stayed at Archives II after the US Workshops were over, in order to devote additional time to writing and revision. The non-Workshop telephone, email and verbal exchanges are sometimes mentioned in the Workshop documents, but they are usually either only briefly summarized or not summarized at all.[21]

Finally, even when detailed documentation, including meeting minutes, are available for Workshops and related activities, the documents provide a relatively filtered account. For example, in some cases, the minutes indicate that a lengthy discussion ensued but then only include the ultimate conclusions or action items resulting from the

[21] There are a few exceptions to this, such as occasional teleconference summary documents or copies of email messages available through the servers associated with the ISO Archiving Workshops.

discussion. Some comments are attributed to specific individuals, whereas others are simply stated as having been part of the discussion. One particularly revealing case of the filtering of reality through written minutes is associated with Fourth International Workshop. There are two different sets of minutes from this Workshop: one covers all of the Panel 2 discussions (dated May 20), and the other is specific to the Archiving workshop (last updated June 20, 1997 and appears to be a revised and expanded version of the other minutes. While the majority of the text in the two documents is identical, there are several notable differences in wording and level of emphasis on issues.

3.4.2 Social Network Analysis

Data based on attendance at ISO Archiving Workshops provide an extremely valuable first approximation of the centrality and influence of both individuals and organizational actors. However, these data alone do not tell a complete story. First, number of meetings does not always correlate exactly with importance or influence. For example, International ISO Archiving Workshops took place within the overall semi-annual CCSDS Panel 2 meetings, and some actors who attended a large number of International Workshops could have done so because they were involved in Panel 2 for other reasons, rather than a strong interest specifically in the Reference Model. Second, raw attendance numbers fail to reflect differences in work roles. Some actors could be attending primarily to gather information, others could be actively involved in writing parts of the Reference Model documents, some could be there to report on their own outside efforts, and still others could be primarily providing administrative support.

I have already discussed some of the issues related to the coding of organizational affiliations, based on complicated organizational structures (see 3.3.3). The analysis of participation based on organizational actors rather than individual actors is also complicated by at least two additional factors. First, given the often tightly coupled relationships between government agencies and their contractors – particularly NASA and companies such as Lockheed, Computer Sciences Corporation (CSC), and Raytheon – it is often difficult to treat them as discrete organizational actors. Second, NASA specifically, the organizational actor most actively involved in the development of the OAIS Reference Model, is not a monolithic entity. NASA was formed in 1958 as a confederation of several pre-existing institutions and organizational cultures, and this internal diversity has been a defining feature of the agency throughout its history (McCurdy, 1993; Rosenthal, 1968; Wallace, 1999). For example, someone from the JPL in Pasadena, California, is likely to have very different experiences, priorities and expectations from someone employed at GSFC in Greenbelt, Maryland; Johnson Space Center (JSC) in Houston, Texas; or NASA Headquarters in Washington, DC.

3.4.3 Analysis of Interview Data

One limitation of self-reports of past events is that human memory is both fallible and sensitive to different interview settings. Interview participants are much better at reporting the “gist” of events than recounting the details precisely. “In whatever way the differences among memories may be conceptualized, what is remembered, and how well, will generally depend critically on the interval between the moment of acquisition and the moment of recall” (Ericsson and Simon, 1980, p.218).

There is no way to completely eliminate such issues, but I have addressed them in three ways. First, I focused in interviews on issues for which participants were likely to have strong memories, such as motivations, perceptions and attitudes of participation and incidents they found particularly critical. Second, I relied on external sources of documentation. In advance of the interviews, I sent participants both a summary of the interview questions and the (for all participants except the 12 core team members, who all attended many meetings and would know how to find the meaning documentation if they chose to do so) documents generated from the OAIS development meeting(s) in which they took part, in order to give them some opportunity to jog their memories before engaging in the interviews.   Finally, I have myself made use of documentary sources to clarify, elaborate or challenge findings from interview data.

3.4.4 Generalizability

Defining the scope of my study in terms of the OAIS development process – and related data sources – provides analytical focus, but it also raises important limitations to my findings. One limitation relates to external validity, i.e. the extent to which the results can be generalized beyond the particular case explored in this study. The set of individuals who took part in the development process are a strongly self-selected sample of the total population of individuals involved in digital preservation work. It is, therefore, not possible to generalize from my findings to that entire population. Based on my document analysis and interviews, I cannot derive conclusions about the motivations or attitudes of those who were not aware of this effort, nor to those who were aware of the OAIS but did not directly take part in the development process. My social network analysis, which is based on the affiliation matrix of ISO Archiving meeting participants, also do not allow me to generalize to the larger network of those involved in digital preservation work.   Future research on diffusion and adoption of the OAIS could be designed to elicit data from such actors.

When considering these limitations, it is important to recognize that a case study research design does not follow the “sampling logic” of a study in which one attempts to generalize to an entire population based on data from a set of respondents who are claimed to be representative of the larger population (Yinn, 1994, p. 47). Using a sampling logic, one might assume that the in-depth examination of a single case only represents an “n of 1,” from which one cannot derive any valuable inferences. Case studies, instead, “are generalizable to theoretical propositions and not to populations or universes” (p. 10).

Perhaps a more serious challenge to this study could be raised in terms of internal validity, i.e. the extent to the data I have collected and analyzed actually measure what I claim they measure. Formal meeting documents can fail to reflect important aspects of the social dynamics involved in a process such as standards development. Lists of actors who attended formal Workshops might miss some key actors whose participation took place outside the Workshops. Interviews can provide biased accounts, both through the characteristics of individual memory and the self-selection involved in voluntary participation (those with views consistent with the majority of other actors involved and final outcome of the process may be more likely to express interest in being interviewed).

I have attempted to mitigate these issues of sampling bias in three ways. First, I have allowed interview participants to discuss the role of actors who did not participate in the ISO Archiving Workshops. Second, I have collected and examined literature that cites and discusses the OAIS. Both approaches have allowed me to investigate conversations taking place outside the Workshops themselves. While application and use of the OAIS are not, in themselves, within the scope of my study, they are relevant when that application and use has then fed back into the OAIS development process. In several cases, examination of external literature has alerted me to issues I would then need to address in my further coding and analysis of the meeting documents. Finally, I have multiple data collection and analysis techniques in order to triangulate the results of my study.

3.4.5 Importance of Triangulation

This study was designed with recognition of the limitations of the three methods discussed above. I have attempted to mitigate these limitations through triangulation (Jick, 1979), both within methods and across methods. Examples of within-method triangulation are consulting multiple document types (meeting minutes, presentations, drafts of the Reference Model) about a specific event and asking interview participants about the same issue but in several different ways (both a pre-interview questionnaire and multiple questions during the interview). Between-method triangulation has allowed me to mitigate the effects of the limitations of individual methods. The use of both documents and interviews has allowed me to develop a more complete picture of the OAIS development process than either method would have allowed on its own. The combination of documentary, interview and social network data has also given me a much better idea of both the roles and influence of particular individual and organization actors.

CHAPTER 4 – NARRATIVE ACCOUNT OF OAIS DEVELOPMENT PROCESS

The following chapter provides a detailed account of the OAIS development process. It is not a comprehensive chronology of Workshops, document changes and related activities. Instead, it presents events and activities that were important to the final outcome or otherwise important in understanding how the process unfolded. Within each stage, I have divided the discussion into issues of work structure and process; participation and input; and content of the Reference Model.

4.1 Summary Introduction

The formal development of the OAIS began with a set of proposals from an employee of the JPL in April 1994 and ended with the publication of the OAIS as an ISO International Standard in February 2003. Within that time span, I have identified five distinct stages of the OAIS development process. Formal development and approval of the standard took place within the CCSDS, which has traditionally represented the interests of space agencies. Development of the OAIS was markedly different from the previous standards development efforts of the CCSDS by being both broader in scope and inclusive of a more diverse set of actors. In order to support this unusually inclusive effort, the leaders of the effort set up a unique meeting and decision making structure. In addition to the well-established semi-annual CCSDS meetings, the OAIS development effort also involved a set of US Workshops, devoted primarily to document development, and Open Workshops, designed to gather input and review from a wider set of actors.

The OAIS development process involved a relatively small and stable set of core actors, but it also involved a much larger set of actors who had more limited Workshop participation. The latter played an extremely important role in the development, review and visibility of the Reference Model. Development of the OAIS involved negotiation over issues such as the scope of the Reference Model, its intended purpose and the definition of basic terms. The development process also involved considerable borrowing and adaptation of ideas and documents already in existence. Over time, common notions about the content of the Reference Model became more established, and the number and extent of revisions to drafts of the Reference Model decreased.

4.2 Division of the Process into Five Stages

The narrative account presented in this chapter is based on a division of the process into five distinct stages (see Appendix 9 - Timeline of Development Stages, Documents and Workshops), which are marked by steps along the formal standardization path within the CCSDS and ISO. As in William Moen's case study of the development of Z39.50, "demarcation between the phases can be characterized in terms of participants, processes, goals and outputs" (1998, p.4-25). The following sections of this chapter present various characteristics and events that set the five stages in the OAIS development process apart from each other. However, the points of demarcation between stages are conventional and somewhat permeable. Their "boundaries are approximations that characterize a difference in emphasis, rather than delineating discrete periods" (Sproull, 2000, p.260). Processes of social evolution generally involve an ongoing stream of small, incremental adaptations. Participants in the development of the OAIS did not fall asleep at the end of one stage and wake up the next morning with a completely different set of expectations, goals and opportunities (Steinberg and Trevitt, 1996, p.3). The stages provide a useful way of understanding how the process unfolded, but the differences that characterize those stages are matters of degree. As one might expect with such a complex and dynamic development effort, there are also occasional exceptions to the general characterizations of the stages.

The first stage (April 15, 1994 – October 10, 1995) involved the initial conception and preliminary groundwork for the standardization effort. The process began when Gael Squibb of the JPL proposed a New Work Item (NWI) related to "archiving space data" to ISO SC 14. This proposal ultimately found a home in another subcommittee of the ISO, which approved it as a NWI. Don Sawyer, Computer Scientist and head of the NASA Science Office of Standards and Technology (NOST), made the case for this effort to NASA management, and he took on the role as leader of the Archiving Work Package. Sawyer and Lou Reich, who worked under contract for the GSFC as Senior Consulting Engineer for the Computer Sciences Corporation, co-authored a very preliminary discussion draft of a reference model document. They worked with John Garrett, who worked under contract for the NSSDC as a Senior Analyst at Hughes STX (ST Systems Corporation), to set up an initial meeting and begin distributing documents related to the effort.

The second stage (October 11, 1995 - April 9, 1997) began with the first public meeting associated with the development of the Reference Model: the First US Workshop. The second stage involved several formative Workshops and drafts of the Reference Model. This period also saw the formation of the core set of frequent participants. Both discussions and documents involved active negotiation over the scope and fundamental elements of the Reference Model. There was a fast turnover between versions of the Reference Model, and each one involved significant changes. Authoring of the document was first by Sawyer and Reich, but then increasingly drawing from contributions of other participants. There was one large Open Workshop in France, which yielded mixed responses, but it did contribute to the development of a community of interested actors in France, including several actors outside of the Centre National d'Etudes Spatiales (CNES), the French Space Agency.

The release of White Book 1 marks the beginning of the third stage (April 10, 1997 – April 30, 1999), which involved document formalization and exposure to a wider group of actors. Turnover between versions of the Reference Model was slower than in the second stage, and changes became increasingly more targeted. Writing assignments became more widely distributed among the core participants. Given this distribution of work and the increasing size and complexity of the Reference Model, more energy and attention was necessarily devoted to the coordination of separate contributions and revisions. Workshops settled into to two fairly distinct sets of activities, with US Workshops devoted to core US team members carrying out the work of document revision and International Workshops devoted to formal review and adoption/rejection of changes. Two workshops from this period (UK and DADs) belong to an important third category: Open Workshops, involving a relatively diverse set of actors, interests and inputs. This stage also included the contribution and review of formal comment documents, generally submitted on behalf of institutions. Several specific topics from the Reference Model were also addressed in separate documents – proposed text to go into the document and "white papers" talking about issues more broadly. These two types of documents were used to carry out the discussion without having to make revisions directly to the Reference Model.

The release of Red Book 1 marks the beginning of the fourth stage (May 1, 1999 – January 1, 2002[22]), which was characterized by even slower turnover between document versions and increasing difficulty in making any substantive changes, due to buy-in, closure and interdependencies between document elements. This stage involved the formal CCSDS approval process, including solicitation of wide public comment. Discussion and citation of the Reference Model in professional literature also increased. Discussions increasingly emphasized support for further standardization efforts to build off of the reference model. The large open workshop during this period, called Archival Workshop on Ingest, Identification, and Certification Standards (AWIICS), was representative of this trend, by involving a new and diverse set of actors but also focusing on a relatively bounded set of potential applications and follow-on activities. The OAIS was released as a Blue Book at the end of the fourth stage.

Finally, in the fifth stage (January 2, 2002 – February 24, 2003), the Reference Model progressed from being a Blue Book of the CCSDS, through the formal ISO process, to publication as an International Standard. This involved voting and endorsement by a different set of actors from those who took part in the first four stages.

[22] The date indicated on the Blue Book is simply January 2002. My analyses by stages requires a more precise point of demarcation, so I have adopted the convention of treating every date after January 1 as part of stage 5 (post-Blue Book publication).

4.3 Stage 1 - Concept and Preliminary Groundwork (April 15, 1994 – October 10, 1995)

> *NASA has the timely opportunity to lead the newly formed Archiving Standards task…*
>
> - Don Sawyer, April 24, 1995

4.3.1 Work Structure and Process in Stage 1

On April 15, 1994, Gael F. Squibb of JPL presented three New Work Item (NWI) proposals to ISO Technical Committee 20 (Aircraft and space vehicles), Subcommittee 14 (Space systems and operations). Among these proposals was one entitled "Space Systems - Archiving space data."[23] Robert Stephens of Computer Sciences Corporation (CSC) sent an email message to Sawyer (among others) noting that, rather than taking it on themselves, SC-14 requested that SC-13 (Space data and information transfer systems) consider pursuing three new work packages, including "archiving space data." In November, the CCSDS Management Council resolved to accept the request for the New Work Item, and submitted the NWI to the ISO, on "archiving space data," which would be assigned to Panel 2.

On April 24, 1995, Sawyer issued a document to NASA management, proposing a new archiving standards effort ("Background Material and Proposal," 1995). Sawyer warns of the preservation risks associated with NASA's "attempts to privatize its data infrastructure" and current computing trends "toward highly distributed archiving environments." He suggests, "NASA has the timely opportunity to lead the newly formed Archiving Standards task…" Sawyer proposes 3 phases: (1) develop a reference

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[23] The other two NWIs were "Space Systems - Mission operations concepts" and "Space Systems - Mission operations functions." The former was taken on by SC 13 and published as an International Standard (ISO 14711) in March 2003. I have been unable to identify what came of the latter NWI proposal.

model, (2) “identify a list of available (or missing) standards” at “each functional area/interface,” and (3) “develop any missing standards that were felt to be cost-effective” and prototype. As the NASA representative to Panel 2 of the CCSDS, Sawyer submitted a document to Panel 2 on April 25 (“Comments on SC 13/14 N36,” 1995), indicating that “we believe that to fulfill it properly will take a significant commitment from the participating agencies…[and] will have to be a separate Panel 2 activity with new resources devoted to it.” He adds that Panel 2 “should prepare an ISO New Work Proposal on this subject while we are in Toulouse so we can get it to the Management Council when they meet in mid-May.” At its meeting in May, Panel 2 approved a new “work package” (i.e. area of standards activity) called “WP 700 Archiving.” The proposed initial subtask was “WP 710 Archiving Reference Model.” (Sawyer, 1995b)

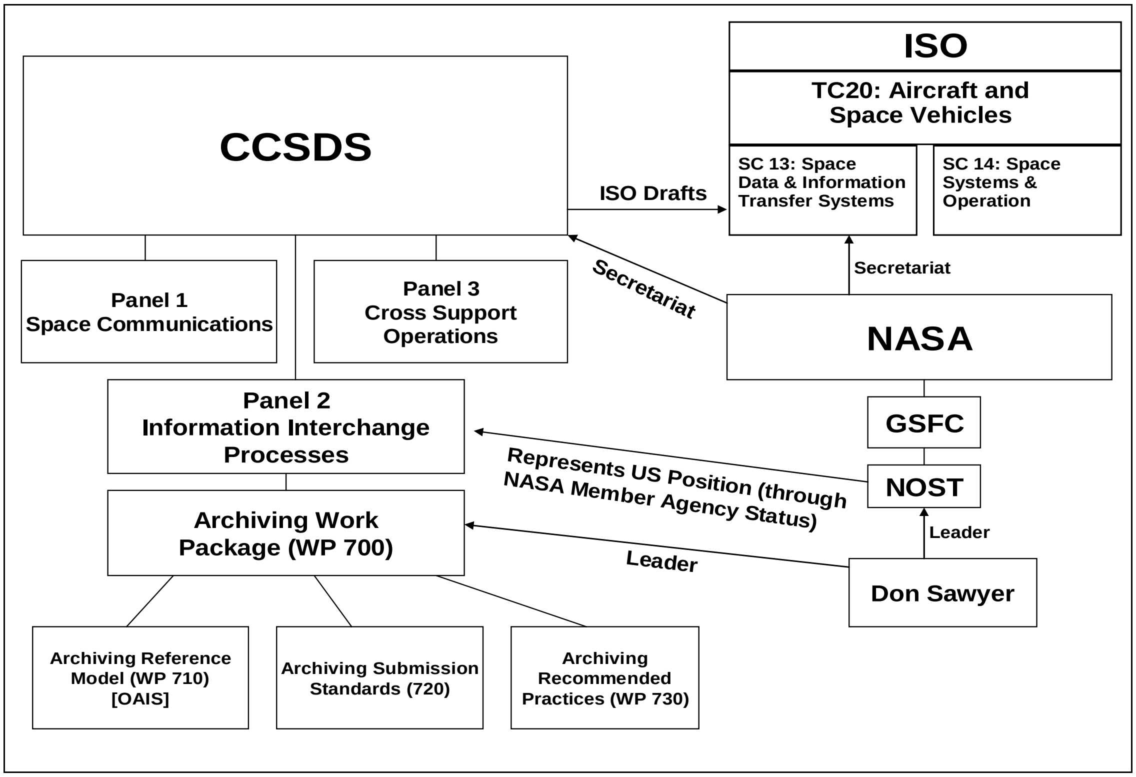

Figure 3 - Organizational Context of OAIS Effort

By June 10, 1995, a web server at the GSFC was providing access to "ISO Proposal for a New Work Item: Archive Model and Services for Space and Related Data."[24] Although this document was advanced within the CCSDS, whose scope was limited to "space data handling standards," this early work item already contains some ambiguity in scope, leaving open the possibility for a wider membership and audience. The New Work Item defines the scope in terms of "digital data obtained from, or used in conjunction with, space missions." The Purpose section, however, indicates that this effort would "encourage commercial support for the provision of archive services which would truly preserve our valuable data, not only for space related data but also for all

[24] The GSFC web space devoted to "ISO Archiving Standards" would serve as the primary public repository of documents related to the development of the Reference Model. It was (and as of the writing of this dissertation, continues to be) administered by John Garrett at GSFC.

long term data archives." The Reference Model is identified as "the first step before adopting or developing specific standards needed to support archive services." Knowledge transfer is also stated as a goal of the digital archiving work package: "These standards will allow new countries entering the space field to have pre-defined formats for the archiving of data and so avoid the learning process and the consequent period of having data that is not easily useable on an international basis."

In September 1995, Sawyer and Reich completed "Digital-Archiving Information Services Reference Model," which came to serve as Version 1 of the Reference Model. In mid-September, Sawyer and Garrett distributed a public call for participation in a "US Workshop on ISO Archiving Standards." Accompanying this announcement was the document from Sawyer and Reich, identified as "the start of a paper (clearly incomplete at this time) defining a view on an Archiving Reference Model. It is provided as a focus for discussion and evolution. It is not intended to preclude any other views or approaches." The announcement states three objectives for the First US Workshop: (1) "Begin the formation of an active US group, composed of Government, Industry, and Academia…" (2) "Advance proposals on the requirements, organization and content" of a reference model. (3) "Provide a forum for the presentation of ideas, issues, and experiences concerning the long term archiving of digital information and the ability of consumers to use that information."

The announcement for the First US Workshop states, "a very aggressive international schedule has been established leading to a draft international standard (DIS) Reference Model in the Spring of 1997." This was consistent with ISO procedures at this time, which stated that ISO Technical Committees and Subcommittees should set target dates for projects that “shall correspond to the shortest possible development times, taking into account the need to produce International Standards rapidly” (ISO/IEC Directives, Part 1, 1995, Amdt 1 1997, p.19).

4.3.2 Participation and Input in Stage 1

In his April 25 message to NASA Management, Sawyer indicates, “We are looking upon this Archiving Task as an opportunity to involve a broad community within the US, in addition to NASA, in formulating our input” (“Comments on SC 13/14 N36,” 1995). In the document he submitted to Panel 2 of the CCSDS, (“Background Material and Proposal,” 1995), Sawyer argues:

> …there will have to be an archive standards effort involving a broad cross section of existing archives and archive users. This will need to include both NASA supported archives as well as archives supported by other federal agencies and by private organizations such as the petroleum companies. It should also include international participation. Involving these players recognizes that we need to leverage the knowledge, expertise, and support from appropriate organizations to jointly arrive at an acceptable suite of archive standards that will have wide recognition and cost-effective support while supporting the incorporation of new technologies. It would not be cost-effective nor particularly practical for NASA to develop such standards on its own, nor would it facilitate access to data from our international and US space partners.

Sawyer later indicates that he knows of no other “task specifically addressing archive standards within ISO, or within any other widely recognized standards body,” and that, therefore:

> This R&D would help establish an archiving infrastructure in the US. The extent to which non-NASA organizations have archiving needs significantly different from ours would have to be assessed as the work progressed. Folding NASA's needs into a broader effort can make the resulting standards more widely applicable, and this is desirable as long as the effort is seen to be cost-effective for NASA.

This foreshadows the participation in US and Open Workshops, which members of the core team were able to cultivate in the US. As explained above, this was an aberration within the CCSDS structure, which generally involved Member Agencies (and to a lesser extent Observer Agencies) taking on the role of representing the interests of their own countries.

4.3.3 Content of the Reference Model in Stage 1

Version 1 of the Reference Model, developed by Sawyer and Reich, is short (approximately 900 words) and includes several section headings that do not yet have any accompanying content. The document begins with four definitions: Archived Data, Archived Information, Information Granule, and Reference Model. Although much of the document's structure and terminology would change throughout the ensuing development process, this very first draft includes several concepts and elements that are reflected – often in adapted form – in the Blue Book. The document includes one figure: a simple ASCII text diagram of a model of "Archival Information Services Interfaces and Relationships," which includes five entities (Ingest, Access, Dissemination, Metadata Management, and Data Storage) and the interfaces between them. This and subsequent iterations of the diagram would serve as a major focus point for OAIS development (see Appendix 7 – Graphical Chronology of Changes to OAIS Functional Model). Several of the entities in the model presented in Version 1 are notably similar to those in the archive model laid out by NASA in the 1960s (see Figure 1). Use of the term "Ingest" also reflects established usage within NASA (Schotz, Negri and Robinson, 1989; Berbert and Kobler, 1992; Bedet et al, 1993; Green, Klenk and Treinish, 1990; Kobler et al, 1995; McMahon, 1994; Tilton, 1994; *PDS Data Preparation Workbook*, 1995), and Metadata

Management matches very closely with Data Management, one of the seven subsystems of the Science Data Processing Segment (SDPS) at DAACS of the EOSDIS (Kobler et al, 1995).

4.4 Stage 2 - Early Meetings and Drafts (October 11, 1995 – April 9, 1997)

> *[The ISO TC20 / SC13] organizational focus does NOT mean that we are restricted to space data archiving only.*
>
> - Don Sawyer, October 11, 1995

This stage was characterized by the formation of the core set of players. During Stage 2, US Workshops were established as primarily working meetings (rather than forums for open exchange or series of presentations) and the Archives II facility of NARA became the primary site for the US Workshops. Sawyer and Reich, the authors of Version 1 of the Reference Model, remained the primary authors and editors of later versions, but the process also increasingly drew from contributions (both text and figures) from other participants. Several actors submitted written comments on the Reference Model (either individually or as representatives of CCSDS Member Agencies) and archives scenarios, intended to map the concepts from the Reference Model to specific contexts. The first Open Workshop (French) also occurred during Stage 2.

There was active negotiation over the scope and fundamental elements of the Reference Model. There were usually significant changes with each new version and fast turnover between document versions (mean time between versions was 2.4 months). Participants had not yet settled on some of the basic terminology, so inconsistent terminology occasionally appeared in the Reference Model (e.g. essentially identical definitions for both Customer and Consumer).

This set of dynamics at the beginning of the formal OAIS development process is consistent with the findings of William Moen, who indicated that an important goal of the early stage of developing Z39.50 as a standard was to “transform the ill-defined problem [of linking systems] into a well-defined problem that could be solved (i.e., an output)” (Moen, 1998, p.5-13). This is what other authors (e.g. Latour) have called “translation work”: moving from a more general normative vision to a specific design for making it a reality.

4.4.1 Work Structure and Process in Stage 2

During Stage 2, there were ten ISO Archiving Workshops: First US Workshop on October 11-12, 1995; First International Workshop on October 26-27, 1995; Second US Workshop on December 19-20, 1995; Third US Workshop on March 19-20, 1996; French Workshop on March 20-21, 1996; Second International Workshop on April 29-30, 1996; Fourth US Workshop on July 10-11, 1996; Fifth US Workshop on October 2-3, 1996; Third International Workshop on November 4-5, 1996; and Sixth US Workshop on January 8-9, 1997.

4.4.2 Participation and Input in Stage 2

With 38 participants, the First US Workshop was much larger than subsequent US Workshops. Although there were some computer industry representatives at the First US Workshop, the discussion was framed primarily in terms of those who were responsible for the ongoing management of digital collections, particularly data archives. For example, the first instruction for the break-out groups on the second days was to “enumerate the standards in use in your archives.”   In a presentation on ISO Archiving

Standards, Sawyer indicated that the "organizational focus does NOT mean that we are restricted to space data archiving only." He expressed a belief that "there is a widespread commonality on basic archiving issues" and there was a "need to start with a broad base of disciplines doing archiving."

Like the announcement for the first US Workshop, the "Call for Presentations / Papers for the First International Workshop,"[25] written by Sawyer, reflects the specific institutional CCSDS context of the work, but also the desire to open and apply the work more broadly. Sawyer indicates:

> I hope that *each of the agencies in CCSDS* that have any involvement in the preservation of digital information, or the provision of this information to those who will archive it, will find a way to generate broad participation in this effort… [W]e should expect this model to be applicable far beyond space or space-related information. Therefore I encourage all the agencies to think about how they can organize to provide the needed expertise. (emphasis mine)

On October 18, 1995, Sawyer gave a presentation entitled "Status of US Contribution to ISO Archive Standards" to the THIC (Tape Head Interface Committee). This was the first of many presentations given by Sawyer and other core participants to outside groups in order to raise awareness of the effort (see Appendix 2). Sawyer indicated an approach that would "leverage the growing, widely distributed, expertise and interest in archiving of digital information" in government, industry and academia.

The announcement for the Second US Workshop does not include reference to "information obtained from observations of the terrestrial and space environments" but instead says "archiving of information, with an emphasis on digital data." However, the workshop web sites continued to include the language about terrestrial and space environments. This announcement document also indicates "some related efforts that are

[25] I was unable to identify the exact date of this document.

generating interesting materials that we need to consider at this workshop": *Preserving Digital Information* and "Metadata Requirements for Evidence." These two documents were also indicated as reference materials for the meeting. At the Second US Workshop, Sawyer agreed to develop responses to *Preserving Digital Information* and "Metadata Requirements for Evidence."

Claude Huc, Chief of the Data Preservation and Enhancement Department of CNES, issued a document in January 1996 entitled "Preliminary classification of metadata: Proposal." Many of the concepts and terms from this document – and a revised version in April entitled "Towards a Metadata Model" – became subjects of workshop discussions and part of drafts of the Reference Model. Most were eventually either dropped or the terminology revised by the time the Blue Book was published, but several conceptual contributions, such as aggregation of digital objects into collections, were vital to the final version of the standard.

The French Workshop in March 1996 was the second largest of all the Workshops, with 52 individual participants, but it was not as organizationally diverse as the other Open Workshops. For all but two of the individuals, this was their first ISO Archiving workshop; and most individual participants did not attend any subsequent Workshops. While there were 22 first-time and 19 one-time organizational actors represented, the set of organizational actors was not as heterogeneous as in the other Open Workshops; only 23 distinct organizational actors were represented by the 52 individuals. This largely can be attributed to the heavy participation of one organizational actor: CNES, the host of the event, represented by 20 (38%) of the individuals at the workshop. One notable presence at the meeting, however, was the

National Library of France (BnF), which sent two representatives, both of whom gave presentations during the first session of the workshop (Huc and Mazal, 1996). Patrick Mazal, Head of the Methods and Procedures Department in the Ground System Projects Directorate at CNES, provided a summary of the French Workshop at the Second International Workshop, which took place approximately a month later. He indicated, "Some participants considered [it] too ambitious to study the normalisation of all archiving activities, as specialists are required in every domain." Mazal said there had been "no commitment to an ISO activity but most participants [were] ready to participate in another workshop to exchange experiences again in a year or two." The French Workshop's "Overview" document on the Web also indicates an expectation to hold national meetings in between the international meetings. In fact, the first French workshop turned out to be the only one.

Shortly after the completion of the Second International Workshop, on May 1, 1996, the final version of *Preserving Digital Information: Report of the Task Force on Archiving of Digital Information* was released. (An earlier draft of the report had been released in August 1995.) This document is cited in the Reference Model (starting with Version 5) and cited as required reading for many of the workshops after this. Both this document and the Reference Model define archives functionally, in order to remain open to a variety of institutional structures that might implement those functions. Like the OAIS, *Preserving Digital Information* also discusses several possible digital preservation strategies but does not commit to any specific one. "No single strategy applies to all formats of digital information and none of the current preservation methods is entirely satisfactory." The OAIS uses several terms and concepts from *Preserving Digital*

Information. For example, the elements of Preservation Description Information (PDI) in the Blue Book are Provenance, Reference, Fixity, and Context information, which are very similar to the list of "features that determine information integrity and deserve attention for archival purposes… content, fixity, reference, provenance, and context" from *Preserving Digital Information*. The report also includes the terms refreshing, migration, digital objects, digital archives, and the notion of "essential features of what needs to be preserved." Despite the overlap in subject matter, there is fairly little overlap in the social networks associated with the Task Force and the ISO Archiving Workshops. At the individual level, only one of the 21 members of the Task Force (Co-Chair, Don Waters)[26] attended any ISO Archiving Workshops. Of the 18 organizational actors with which members of the Task Force were affiliated, only five of those organizational actors were represented at one or more ISO Archiving Workshops.[27]

On September 17-19, 1996, the Fifth NASA Goddard Conference on Mass Storage Systems and Technologies (MSST) took place in College Park, Maryland. Huc, Thierry Levoir and Michel Nonon-Latapie of CNES co-authored a paper for the conference "Long-Term Archiving and Data Access: Modelling and Standardization," which reports on a study at CNES "of the problems posed by long-term archiving." The CNES study included the formulation of design principles and then an archival system prototype in 1995. Issues of technological obsolescence

> led us to look for a solution in terms of a general model for a long-term archival service which would be totally independent of technological advances. Other teams, in particular in the USA, have taken a similar

[26] The other Co-Chair of the Task Force was John Garrett, who was then Chief Executive Officer of CyberVillages Corporation. Note this is not the same John Garrett who served as contractor to GSFC and acted as a member of the core US team in the OAIS development effort.
[27] The five organizational actors are LC, NARA, National Agricultural Library, OCLC, and RLG.

> approach and it soon became clear that we shared a common view of the problem on the first level of the model.

The paper lays out the CNES archival service model, which is based directly on the ISO Archiving Reference Model of the time (Version 4).

According to the minutes of the Third International Workshop on November 4-5, in Sawyer's presentation on *Preserving Digital Information*, he said that its recommendations "are at a high level but identified a lot of concepts that the Archive Reference Model Group is addressing." He concluded that "the paper is a good statement of the 'archiving problem' that is the basis for our work," "we need to establish dialogue with this group and others such as the Z39.50 effort on access to digital collections," and "Version 7 of Reference Model draft reflects much of their concepts and terminology." In relation to Version 7, the minutes also indicate that the document references the "problem statement" provided by *Preserving Digital Information*. It says, "The AIPs are based on concepts from the Z39.50 Digital Collections family," and "the Information Model is compatible with Z39.50 Digital Collections family of profiles."

The minutes of the Sixth US Workshop, which took place on January 8-9, 1997, make a special note of welcoming Gerald Gibson from the Library of Congress (LC) as a new participant. Gibson did not attend any workshops after this, nor did anyone else from LC. It would be about a year and a half before any libraries or library-related organizations were again represented at a Workshop.[28]

On March 11, Randal Davis, from the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado, distributed "an updated white paper on

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[28] The DADs Workshop (June 22-26, 1998) included participants from RLG, National Agricultural Library (NAL), Coalition for Networked Information (CNI), Digital Library Federation (DLF), Georgia Tech Library, and Southeastern Library Network (SOLINET).

Data Migration reflecting comments from the last telecon[ference] we had," which would become the "Migration Perspectives" section of White Book 1. In this document, Davis introduces what would often later be discussed as the "equivalence principle":

> The general rule for data migration is that information content should be preserved although the data itself may change. The information content of a copied dataset is 'equivalent' to the original if there is a known transformation that can generate the original information from the copy.

This was presented and discussed as a principle in White Book 1 and several versions of the Reference Model after this. Although the Blue Book does not include it explicitly as a principle, it is an essential element of the definitions of Reversible Transformation and Non-Reversible Transformation.

4.4.3 Content of the Reference Model in Stage 2

There were 7 versions of the Reference Model in Stage 2: Version 2 on December 19, 1995; Version 3 on March 11, 1996; Version 4 on April 22, 1996; Version 5 on July 5, 1996; Version 6 on September 23, 1996; Version 7 on October 25, 1996; and Version 8 on January 6, 1997.

Several fundamental concepts of the Reference Model were introduced during Stage 2, including "designated communities" or alternatively "designated user community" (Version 2); the idea of "minimizing information loss" (Version 4); "representation" (Version 2); "package" (Version 3), "information package" (Version 5) and "archive information package/object" (Version 6); and OMT diagrams and accompanying descriptions of Archival Information Packages (AIPs) as being composed of Content Information and Preservation Description Information; and Content

Information as being composed of Data Objects and Representation Information (Version 7).

The general trend during Stage 2 was toward adding new text and making significant changes to each version of the Reference Model. Version 5 is the only version of the Reference Model during Stage 2 to be shorter than its predecessor. As evidence of the growing need for coordination of the development of various parts of the document, Version 3 is the first to include a set of change tracking notes. These notes, which appear in all subsequent versions through White Book 5, provide an informal and selective explanation of notable changes and (sometimes) areas needing further work. The notes (except for those for Version 6) begin with the salutation "Dear Reader."

At the first US Workshop and several subsequent Workshops, the leaders of the effort called for the development of "scenarios" that applied the reference model concepts to specific repositories or collections. Participants generated several such scenarios throughout the OAIS development process, and a subset of them became Annex A in the Blue Book. The need to demonstrate the application of the Reference Model to actual repositories was a strong theme throughout the development process. It was consistent with the statement made by Sawyer in his April 1995 proposal to NASA management: "The usefulness of the Reference Model would be partly checked by mapping a number of existing archives against the model." Participants in the Fourth US Workshop generated an outline to be used in generating archive scenarios. Version 6 is the first version to include text about existing archives in the "Scenarios" Annex (Annex A): two based on collections at the U.S. National Aeronautics and Space Administration (NASA) and one based on collections at the U.S. National Archives and Records Administration

(NARA). Version 7 includes a new "illustrative scenario" written by Randal Davis, which "describes the flow of information into and out of a hypothetical archive of space science data," which remained in the Reference Model until White Book 1.2.

During Stage 2, the Reference Model went through a series of title changes, and then took on the title that it would carry throughout the rest of the process. The title of Version 1 is "Digital-Archiving Information Services Reference Model," but Version 2 is then called "Reference Model for Digital Archiving Standards." The title of Version 3 was again changed, this time to "Reference Model for Archival Information Services." The title of Version 5 changed yet again, to become "Reference Model for Archival Information Systems." Finally, Version 6 reflects the final title change for the document: "Reference Model for an Open Archival Information System" (with the word "Open" presented in italics, in order to alert readers to the change).

An issue that arose repeatedly in the development of the Reference Model is what technical and organizational elements are within the scope of an archive and which are related but considered part of the environment (and thus, by implication, outside the direct realm of competence and responsibility of an archive). Version 2 of the Reference Model lays out two layers: "generic services layer, which can be used to support a large number of computerized applications, and an archival services layer, which is tailored for use by digital archiving applications." The Generic Services layer contains two entities: policy management entity and common services. The Generic Services layer (and with it, the Policy Management entity) is dropped in Version 7, but the term Common Services remains in the Blue Book. The location, treatment and appearance of Common Services, policy, management and administration within the Reference Model were ongoing issues of discussion and revision. Along with security, these concepts moved around at the intersections, and often at the periphery, of the other core entities and services of the Reference Model.

Stage 2 included discussion and consideration of several external documentary artifacts. Version 2 of the Reference Model includes the addition of text related to the "Reference Model for Business Acceptable Communications," which was a product of an electronic records research project conducted at the University of Pittsburgh, funded by the National Historical Publications and Records Commission (NHPRC) (see Duff, 1996, 1998) and widely cited in the literature of the archival profession on electronic records. Language from the "Reference Model for Business Acceptable Communications" was dropped in Version 3.

Version 3 includes a substantial portion of text taken from the "Z39.50 Profile for Access to Digital Collections" (DCP). With this text comes the introduction of several terms and concepts.[29] At the Third US Workshop, Davis and Sawyer both expressed concern about the appropriateness of the current inclusion of so many details of Z39.50 DCP in the Reference Model. At the Second International Workshop, Davis suggested that the content drawn from the Z39.50 DCP "may be too specific." Reich also indicated the need to examine the Z39.50 DCP, Catalogue Interoperability Protocol (CIP) and Huc's proposed metadata model and then "come to a common model."

Version 5 eliminates most of the detailed language previously introduced from the Z39.50 Profile, though several concepts such as Collection and Result Set make it all the

[29] Many of these terms and concepts were well established within the library and archives professions, but it is important to note that the Z39.50 profile was introduced because of its use within the context of "archives for Earth Observation disciplines." It was not a reflection of active involvement of librarians or institutional archivists, which generally did not occur until much later in the OAIS development process.

way into the Blue Book. At the Fourth US Workshop, Sawyer again expressed concerns, stating that "Z39.50 is coming out of libraries with focus on data access, not on preservation as is this activity." The Dear Reader notes of Version 6 suggest that the version's new data model, based on an "archive information package/object," which "the authors feel may be a breakthrough in relating our work to other major digital library and digital archive efforts." It allows the Reference Model to "incorporate much of the functionality of the 'Z39.50 Profile for Access to Digital Collections' and the classes of metadata described" in *Preserving Digital Information*, but one of the "known problems" is that there is still "too much emphasis on the digital collections profile as a starting point rather than using the requirements of archiving to derive the model." In Version 7, Annex C includes "material on the relationships to the Z39.50 work [that] was taken from version 6 so as not to get lost."

Version 3 includes a "Specialization of the Digital Collections Model for Earth Observation (EO)," which identifies two types of collections (singletype and multitype), and four types of descriptive items (DIs): directory, inventory, guide and browse. These four types also appear in an earlier paper by Huc (1996), which was, in turn, drawing from a Committee on Earth Observation Satellites (CEOS) document (Catalog Subgroup, 1993).

Version 3 also includes the introduction of an operational description of data ingest, written by Mike Martin, Principal, Advanced Technology Research and Development at JPL. This text introduces language that aligns closely with parts of the *Planetary Data System Data Preparation Workbook*, which is a publication of the JPL. For example, this new section of Version 3 of the Reference Model states, "It is assumed that an archive package will go through a peer review process for validation prior to submission to the archive." This is an assumption based on the practices and procedures addressed in the *Workbook*. In Version 4, the producer-archive and consumer-archive interactions become much more explicit, with the introduction of several concepts that were already in use at the Planetary Data Service (PDS) as evidenced by Mike Martin's "PDS Scenario," July 22, 1996.

Version 5 is the first version to contain content in a formal References section. It contains only one citation: "Preserving Digital Information." Version 5 also includes the first discussion of "provenance, or the need to document the historical context of an IO [Information Object] before it came to the archive as well as any changes to it while it is within an archive." Provenance is one of several terms from "Preserving Digital Information" that would become an integral part of Preservation Description Information (PDI) in the Reference Model.

The developers of the Reference Model attempted to keep its content general enough to be apply to various types of archives. However, this raised the question of whether or not the Reference Model should explicitly identify differences between particular types of archives and data, or instead leave out discussion of those differences in order to frame all language within the document more inclusively. Stage 2 included the introduction of two such distinctions. One would then remain in the Reference Model and the other would ultimately be dropped. Version 4 introduces an overview of the distinct role of "traditional archives," which are responsible for government records. Although it undergoes some minor revisions in later versions, the text about traditional archives remains substantively similar all the way into the Blue Book. Version 4 also introduces definitions for "document" and "observational data" and lays out a distinction between the two later in the document.[30] The explanation of this distinction is dropped in Version 5, and the definitions for the two terms are removed from the definitions section in White Book 1 (during Stage 3). The abandonment of the document vs. observational data distinction reflects an orientation toward developing terms and concepts that could be broad enough to be inclusive of various forms of information, rather than developing separate terms and concepts for each.

4.5 Stage 3 - Document Formalization and Wider Exposure (April 10, 1997 – April 30, 1999)

> *Over the long run we are unlikely to be the leaders of the archive work. However in the short-term we are, for whatever reason, in the spotlight [and] we should take advantage of that.*[31]

Activities during Stage 3 further solidified the trend of US Workshops being devoted primarily to the work of document revision by a small team of active participants and International Workshops being devoted primarily to review and adoption of changes to the Reference Model. During Stage 3, writing assignments were more widely distributed across the team of core participants. The leaders received several written comments on versions of the Reference Model (White Books), usually submitted on behalf of organizational actors. Several specific topics from the Reference Model were also addressed in separate documents – proposed pieces of text to go into the document

[30] This is a similar distinction to the one between "data files" and "text documents" in the National Archives and Records Administration's "Standards for the Creation, Use, Preservation, and Disposition of Electronic Records" (36 CFR 1234.20-22), which was effective June 7, 1990. NARA had introduced this distinction on December 5, 1988 as part of a proposed rule change (53 FR 48936), in the form of "data bases and numeric data files" versus "text information in an office automation system."

[31] Seventh International Workshop Minutes

and “white papers” talking about issues more broadly. These two types of documents allowed participants to carry out the discussion without always having to make revisions directly to the Reference Model. There were two Open Workshops during Stage 3 – one in the UK and one in the US – designed to draw from a wide set of interests and get broad input. Promotion of the Reference Model appeared to be paying off, with the first coverage of the Reference Model in professional literature.

The content of the Reference Model was more stable than in Stage 2, but there will still some exploratory changes, which resulted in the addition and then abandonment of terms and concepts. Changes between versions of the Reference Model were more targeted, and the turnover between document revisions was slower than during Stage 2 (mean time between versions was now 3.6 months). There was one fundamental change to the functional model: the combination of Access and Dissemination into a single entity.

4.5.1 Work Structure and Process in Stage 3

There were thirteen Workshops during Stage 3: Seventh US Workshop on April 16-17, 1997; Fourth International Workshop on May 12-14, 1997; Eighth US Workshop on July 16-17, 1997; UK Workshop on September 10, 1997; Ninth US Workshop on September 30 – October 1; Fifth International Workshop on October 27-29, 1997; Tenth US Workshop on January 28-30, 1998; Eleventh US Workshop on April 1-3, 1998; Sixth International Workshop on May 13-16, 1998; Digital Archives Directions (DADs) on June 22-26, 1998; Thirteenth US Workshop on September 16-18, 1998; Seventh International Workshop on October 26-30, 1998; and Fourteenth US Workshop on December 16-17, 1998.

4.5.2 Participation and Input in Stage 3

Although CCSDS procedures do not call for external circulation of documents during the White Book phase, discussions at the Fourth International Workshop on May 12-14 indicate that White Book 1 of the Reference Model was being presented to numerous actors not directly involved in the development effort. The Fourth International Workshop minutes state that White Book 1 “is being used in promotional activities within NASA.” Sawyer also discussed promotional activities with Research Libraries Group/Digital Archiving Task Force, NSSDC, Space Operations Management Office (SOMO) Data Archiving and Distribution Panel, and Society of American Archivists (SAA). The activities revealed interest in the Reference Model by some external actors, but also a “major concern” about “how this model would work with other federated systems which are underway.”

According to the web page for the “First UK Workshop,” which was hosted by the BNSC on September 10, 1997, the purpose was “to disseminate information to UK industry and UK governmental institutions about archival information systems standards that are currently developed” within the CCSDS and ISO. The UK Workshop was large, with 49 individual participants, but it was the least diverse of the Open Workshops in terms of unique organizational actors represented. Like the French Workshop, most of the individuals were first-time participants, and few attended any other ISO Archiving Workshops. All but four of the individual participants were from the UK; three were from France, and one was from Italy. The largest contingent of members (17) were from the Defence Evaluation and Research Agency (DERA), which was a component of the UK Ministry of Defence, responsible for scientific advice, technical support and research.

Compared to other OAIS Archiving workshops, this one included a large portion (17 participants or 35%) from the private sector. The company with the most representation was Logica, who sent 7 individuals. Logica was one of the two contractors to develop the first-phase CIP Specification (CIP-A), and the UK Workshop included a session and demonstration devoted to CIP.

On September 16-17, 1997, the IEEE held its Second Metadata Conference in Silver Spring, Maryland. At this conference, Huc, Thierry Levoir, and Michel Nonon-Latapie presented a paper on "Metadata: models and conceptual limits." This paper describes a data model developed at the CNES. It reports an "obvious convergence" between the CNES data model, the Reference Model and "the framework of CEOS work on the CIP."[32] The authors explain that the creation of the Data Center for Natural Plasma Physics (CDPP - Centre de Données pour la Physique des Plasmas Naturels)[33] in France would make use of the data model presented in this conference paper.

At the Ninth US Workshop on September 30 – October 1, 1997, Sawyer and Ambacher, Archives Specialist at NARA, reported on their attendance and presentations to the Society of American Archivists Annual Meeting, indicating their "impression that [the] community is, as a whole, just getting their feet wet with electronic forms of data despite considerable experience at some archives such as NARA. Digital libraries appear to be the major archival thrust for forming views on preservation of electronic forms." At the Ninth US Workshop, there was also considerable attention paid to the importance of related outside documents and the value of maintaining consistency with them.

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[32] Interoperable Catalogue System, User Requirements Document, CEOS Document CEOS/WGISS/PTT/ICS-URD-B, January 1997.

[33] The version of the Reference Model released later in the same month – White Book 1.2 on September 29 – included a new "scenario" related to the CDPP as part of an annex.

Like the previous International Workshop, there was considerable discussion at the Fifth International Workshop on October 27-29, 1997, of liaison activities and relationships with other related activities. The minutes state, “It is important to try to co-ordinate with RLG,” who had expressed “interest in the Reference Model.” Reich expressed that the Reference Model “is mature enough now to present to any other bodies.” David Giaretta, Chair of CCSDS Panel 2 from the Rutherford Appleton Laboratory (RAL), also “reported that people concerned with archiving of cultural information had expressed interest during the UK workshop. It was suggested that it may be useful to give the OAIS presentation at some conferences on cultural heritage, early next year.”

Participants in the Fifth International Workshop also discussed two additional work packages that had been defined at the Fourth International Workshop: WP 720 – Archiving Submission Standards and WP 730 – Archiving Recommended Practices. WP 720 was reported as being “in the Management Plan.” WP 730 was planned to be “modeled on ISO9000.” Reich “expressed concern that we must attempt to be inclusive, and not omit certain areas simply because the proponents of e.g. STORAGE, have already dropped out of the OAIS development process” (emphasis in original). Reich suggested planning a large workshop “to try to draw in others, and especially vendors.”

A little more than one month after the Fifth International Workshop, Neil Beagrie, Collections and Standards Development Officer for the Arts and Humanities Data Service (AHDS), and Daniel Greenstein, Director of the AHDS, released Version 2 of the “Guidelines for Digital Preservation: Draft Data Policy Framework Document,” (Arts and Humanities Data Service, December 8, 1997). It indicates, “We intend to explore the compatibility and relevance of the work undertaken by the ISO OAIS working party on behalf of the Space and Earth Observation communities to our own study and other digital archives." This is the first instance I have identified of what would come to be an extremely active stream of discussion about the Reference Model in the literature of interested professions, written by individuals outside of the main OAIS development team. Greenstein would later presented a position paper (coauthored with Beagrie) at the DADs workshop (June 1998) about this AHDS document.

In January 1998, Sawyer issued two related documents: "An Analysis of Information Migration" on January 25 and "Addendum to: An Analysis of Information Migration" on January 26. The purpose of the first paper is "to provide a more detailed assessment of the migration problem and its relation to OAIS data modeling concepts." Sawyer lays out four distinct approaches to migration. Several of the concepts from this paper appeared in later versions of the Reference Model, though sometimes using different language. Sawyer wrote the second "Addendum" document to address what he saw as some of the "weaknesses" of the above document. The next day, January 27, Reich issued a document entitled "An Analysis of Levels of Interoperability." This document lays out "four categories of archives," based on their level of integration: independent, cooperating, federated and distributed.

At the Tenth US Workshop in January 1998, there were discussions of several liaison activities. One was US CODATA (Committee on Data for Science and Technology) Conference, where Don Waters, Director of the Digital Library Federation (DLF), and Clifford Lynch, Director of the Coalition for Networked Information (CNI), presented on the *Preserving Digital Information* report and both "expressed interest in getting involved with [the] upcoming workshop." Other liaison activities reported at the Tenth US Workshop were National Association of Government Archivists and Record Administrators (NAGARA), RLG, JISC and British Library (indicating that Neil Beagrie "is interested in OAIS and is also looking for a bibliography of Archive-related papers").

In February 1998, Sawyer issued two documents: "Regarding Migration and the Preserving Digital Information Paper" on February 3 (updated and expanded on March 4) and "Separating Content from Packaging, and Repackaging" on February 5 (also updated and expanded on March 4). In the first, Sawyer states, "I have been taking another look at the Preserving Digital Information (PDI) paper, and I urge all of us to give it a second reading."

On April 7, 1998, a few days after the Eleventh US Workshop, Sawyer sent an email message to CCSDS Panel 2 with the subject: "Key Archive Reference Model Issues." Sawyer states, "We have been attempting to partition the functionality among Access, Dissemination, and Data Management. We have come to the conclusion that there are too many optional ways to do this, and picking one results in the flavor of an implementation, not a refernece [sic] model." He adds, "We certainly don't want to add more boxes, so we have come to the unanimous conclusion" among Sawyer, Reich, Garrett, Robert Stephens, Paul Grunberger, Mike Martin, and Ambacher "that we should merge the Dissemination function and the Access function into one box called 'Access and Dissemination'."

May 1998 saw active preparation for the large, open workshop, which, some time before the Eleventh Workshop, had been given an official name: Digital Archive Directions (DADs). Preparation included the dissemination of the "DADS Workshop

Position Paper Submission Form" on May 13, which allowed individuals to propose papers to report on projects or related standards efforts.

On June 22-26, 1998, the DADs Workshop took place, and it was the most attended of all Workshops, with 55 individual participants and 40 different organizational actors represented. For most of the individual participants, this was the first and only ISO Archiving Workshop they attended. Fifty of the individuals were from organizations in the United States, while 3 came from the UK and 2 from Canada. Participation in the last 3 days of the Workshop was limited to those whose position papers had been selected by the DADs Workshop Program Committee.

At DADs, WG 2 indicated that "the following activities should be monitored for the benefit of the digital archival community": MPEG-7, DOD 5015.2-STD, Metadata for Interchange of Files on Sequential Storage Media Between File Storage Management Systems (FSMS) (ANSI/AIIM MS66-1999), and IEEE Storage System Standards Working Group (SSSWG).[34] Working Group 1 recommended review of the Reference Model "by selected individuals from the science, library, and archival communities" in order to reduce "jargon [that] may be unfamiliar to some target communities."

Also at the Seventh International Workshop, Reich said, "We clearly need an architecture within which other groups will work. Some of this may be in the Reference Model already." The minutes later state, "Over the long run we are unlikely to be the leaders of the archive work. However in the short-term we are, for whatever reason, in the spotlight [and] we should take advantage of that." Sawyer then suggested, "we may

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[34] Of the 155 individuals who took part in one or more of the 49 SSSWG meetings between July 1990 and August 2002, 6 also attended one or more ISO Archiving Workshops; 3 attended several workshops, and 3 attended only one.

not have a wide-enough representation to draw up such an architecture." Reich responded that "we do not have time to wait for such a wide consortium – we should draw up a 'base document' as input to such a consortium."

In relation to the DADs Workshop, the Seventh International Workshop minutes state that there were "people keen to continue workshops to coordinate between groups." This echoes a statement in the DADs Workshop report: "There was a desire for another workshop, involving key participants from a variety of organizations who did not participate" in DADs. On the agenda for the Fourteenth US Workshop was a discussion of "'Open Archives Workshop' plans." Both items appear to indicate early discussion of what would become the Archival Workshop on Ingest, Identification, and Certification Standards (AWIICS), held on October 13-15, 1999, during Stage 4.

In April 1999, Gail Hodge and Bonnie C. Carroll of Information International Associates, Inc., issued a report, "Digital Electronic Archiving: The State of the Art and the State of the Practice," which was the product of a study sponsored by the International Council for Scientific and Technical Information (ICSTI) and CENDI (Commerce, Energy, NASA, NLM, Defense and Interior), a group of U.S. federal scientific and technical information managers. The report indicates that the state of the art on digital archiving at the time provided many "building blocks for future developments," but there was a need for further coordination across the activities within different disciplines and nations. The report discussed the Reference Model as a very promising standard for the coordination of digital archiving activities, but commented that the Reference Model (White Book 4) was "still very data-centered. ICSTI should convene a small group or groups of stakeholders to interpret the reference model for the different communities – primary publishers, secondary publishers, and libraries."

4.5.2.1 CEDARS

In April 1998, the CEDARS (CURL Exemplars in Digital Archives) project got underway. According to the "Cedars Project Report: April 1998 – March 2001," "Although the original project proposal did not refer to the OAIS model specifically, soon after the project began it became clear that work on OAIS was relevant to the project's plans for a demonstrator" (Cedars Project Team, 2001, p.9). As early as August 1998, CEDARS project products were drawing from the Reference Model (Day, 1998), which was now White Book 3. The Reference Model

> provided the Cedars project with a welcome set of well articulated concepts and a comprehensive vocabulary. These have allowed the project to communicate across the partner sites (and across disparate technical backgrounds) and discuss the implementation of a demonstrator archive. (CEDARS Project Team, 2001, p.12)

CEDARS project member David Holdsworth would later issue formal comments (RIDS) about the Reference Model to the CCSDS.

4.5.2.2 NEDLIB

NEDLIB (Networked European Deposit Library) was a project that aimed "to develop a common architectural framework and basic tools for building deposit systems for electronic publications (DSEP)." The project was initiated on January 1, 1998, by CoBRA+, a committee of the Conference of European National Libraries (CENL), with funding from the European Commission's Telematics Application Programme. The project was led by the KB and involved eight national libraries in Europe, one national archive, three publishers and two other organizations (van der Werf-Davelaar, 1999).

On November 24, 1998, Titia van der Werf of the National Library of the Netherlands (Koninklijke Bibliotheek - KB) and project coordinator for NEDLIB submitted a document (van der Werf, 1998) to the other leaders of the project, proposing that they reorient their work by basing it on the OAIS. In this document, van der Wef raises "issues of coherence" (p.1) across the various activities of NEDLIB and suggests that adopting the OAIS as the basis for their work could help provide the "necessary glue" (p.2) currently missing from the project. She also indicates that "there are an increasing number of projects carrying out similar work elsewhere and that some have yielded results from which NEDLIB could benefit substantially and which could lead to interesting collaborative efforts" (p.2) She points out that one such project was CEDARS, which planned to demonstrate technical approaches based on the OAIS. In addition to drawing from the Reference Model, van der Werf proposes contributing input into the reference model development effort, including the dissemination of information about NEDLIB adoption of the OAIS at the Eighth International Workshop in May 1999.[35]

At a meeting in Paris on December 4, 1998, van der Werf presented a first draft of a document entitled "Mapping NEDLIB to OAIS." At the meeting, the NEDLIB project team decided to adopt the OAIS as the basis for its work, including the architecture of the DSEP. A second draft of "Mapping NEDLIB to OAIS" by Lex Sijtsma on January 21, 1999 indicates the NEDLIB project can use the OAIS to coordinate its work because the Reference Model is "a complete system" (p.2). This mapping document indicates aspects

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[35] Van der Werf did later provide written comments to the CCSDS (through the CNES as a member agency) on June 2000 and gave a presentation at the Eleventh International Workshop in November 2000.

of the Reference Model that the project could use and those that it may not want to embrace, based, in most cases, on falling outside the scope of NEDLIB's work or on the perception that addressing those aspects of the Reference Model would be too expensive. Another reason for not adopting the entire information model is the impression that "their ideas about this subject" were not yet "finalised" (p.8).

The NEDLIB Annual Report for October 1998 – September 1999, indicates that the "work done in 1999 on the high-level design of a DSEP, based on OAIS, has been done in close concertation [sic] with the OAIS-people and other memory institutions doing similar work based on OAIS." The annual report indicates that the NEDLIB team had been engaged in fruitful conversations with other "OAIS-implementors," including the National Library of Australia (NLA), CEDARS and the British Library.

4.5.2.3 PANDORA

The NLA became interested in the Reference Model, because of its work on a project it initiated[36] in 1996 called PANDORA (Preserving and Accessing Networked Documentary Resources of Australia), which is charged with developing and preserving a collection of Australian online publications. The NLA began adding items to the PANDORA collection in October 1996. In the 1996-1997 period, the project developed a "Logical Data Model" and "Business Process Model." In comparison with the CEDARS and NEDLIB projects, which based their work directly and explicitly on the terminology and concepts of the Reference Model, the PANDORA relationship with the Reference Model is more one of review, attempts to map the Reference Model to its own

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[36] The State Library of Victoria joined PANDORA in 1998, and nine other partners eventually joined the project.

situation and comment rather than direct application and testing of the Reference Model. The PANDORA Logical Data Model, Version 2, November 1997, cites the Reference Model as a "related initiative," but does not make direct use of any of the Reference Model's terms or functions. The PANDORA Business Model does not cite or mention the Reference Model, and it does not appear to make use of any OAIS terminology or concepts. According to comments on the OAIS[37] issued by the NLA (2000):

> While the Library's requirements are not based directly on the OAIS Reference Model, it was used as a check list to ensure that all functions, entities and relationships were included. The National Library of Australia has also formed links with other national libraries and research organisations around the world engaged in similar work, including the NEDLIB and Cedars projects.

4.5.3 Content of the Reference Model in Stage 3

There were seven versions of the Reference Model available during Stage 3: White Book 1 on April 10, 1997; White Book 1.1 on July 5, 1997; White Book 1.2 on September 29, 1997; White Book 2 on October 15, 1997; White Book 3 on April 15, 1998; White Book 4 on September 17, 1998; and White Book 5 on April 21, 1999.

A period of particularly active revision to the Reference Model came between White Book 1 and White Book 2, based on decisions made at the Fourth International Workshop. White Books 1.1 and 1.2 were interim working versions, which had known inconsistencies and reflected only part of the round of changes agreed to at the Fourth International Workshop. When White Book 2 was released, both the body of the text and the annexes included numerous changes. There is only one sub-section of the entire

[37] The NLA's comments on the OAIS point out that Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) is a CCSDS Observer Agency.

White Book 2 document that does not include revisions (1.3 Rationale), and many sections appear to contain completely or almost completely different content.

White Book 5, the last version in Stage 3, and the final version before reaching Red Book status, is largely devoted to refinement of existing elements of the document, rather than adding or removing elements. It is the document with the largest number of revisions to figures (25 of 38, or 66%), yet there are no figures added or dropped. In the definitions section, there is only one new defined term (Refreshment), four changed definitions and no dropped definitions.

By the time it reached White Book 1, the Reference Model was a long and complex document: 98 pages (29426 words) long, containing 20 figures, 69 terms in the definitions section, and multiple annexes. Activity at the Seventh US Workshop revealed the increasing difficulty of managing the interdependencies between the various elements of such a long and complicated document. Participants pointed out terms in the definition section that may no longer be discussed in the text and "orphan flows which probably result from previous text." Grunberger, who had been doing work on data flow diagrams for the Reference Model, circulated proposed edits to Section 3, which had been generated during an earlier teleconference. In a note attached to the revised section that he shared at the Seventh US Workshop, Grunberger explains that he added labels after each of the data flows, with the labels matching the diagrams in the Reference Model.

> I recommend that we carry the labels forward through at least a few revisions of the Model. Maybe you could help us during this time to find a home for deserving 'stray' flows (those currently lacking text support). If a stray is not placed in a home within the next year or so, we'll probably have to put it to sleep.

At the Ninth US Workshop, Randal Davis indicated that he “did not like Content Information and Context Information used so close together, but we did not see viable alternatives given that [the] Information Preservation paper [*Preserving Digital Information*] terms are widely used now.” In *Preserving Digital Information*, “their Context Information included our Packaging Information. We pulled out the packaging information to keep the Preservation Description Information more inviolate for some types of migrations.” At the Tenth US Workshop, there was again discussion of how elements of the Reference Model related to *Preserving Digital Information*: “Context, as stated in Preserving Digital Information paper, included what we now have in Packaging Information.”

4.6 Stage 4 - Becoming a CCSDS Recommendation (May 1, 1999 – January 1, 2002)

Stage 4 included the formal CCSDS approval process, including solicitation of public comment. Within the Workshop, there was an increasing emphasis on further standardization efforts to build off of the Reference Model, rather than specifically focusing on the development of the Reference Model itself. There was also a dramatic increase in professional literature citing and discussing the Reference Model.   Turnover between document versions was even slower than during Stage 3 (mean time between versions was now more than 8 months).

4.6.1 Work Structure and Process in Stage 4

There were 13 Workshops during Stage 4: Eighth International Workshop on May 11-13, 1999; Fifteenth US Workshop on June 10-11, 1999; Archival Workshop on Ingest, Identification, and Certification Standards (AWIICS) on October 12-15, 1999; Ninth International Workshop on November 9-10, 1999; Tenth International Workshop on May 12-15, 2000; Seventeenth US Workshop on July 19-20, 2000; Eighteenth US Workshop on September 14-15, 2000; Eleventh International Workshop on November 1-3, 2000; Nineteenth US Workshop on February 20-23, 2001; Twentieth US Workshop on April 10-11, 2001; Twelfth International Workshop on May 14-16, 2001; Digital Curation on October 19, 2001; and Thirteenth International Workshop on October 22-24, 2001.

At its Spring 1999 meeting, SC 13 approved the submission of the Reference Model as a Draft International Standard (DIS). DIS is the first stage in which a document is distributed through ISO for review and vote. The Reference Model was not actually submitted to ISO until August 6, 1999. At the Tenth International Workshop on May 8-15, 2000, Panel 2 "underlined the point that the delay in ISO distributing the OAIS document is threatening to cripple the OAIS work – the momentum has to be maintained. The danger is that our credibility could be fatally undermined." This was followed by an action item for Giaretta to "bring the delays in ISO distribution of OAIS to MC [Management Council] attention." The minutes later report:

> Major concern that ISO review of OAIS has not yet started. There is a reluctance to press the groups who are known to have RIDS to submit them <u>before</u> the review period has started. RS [Robert Stephens] will try to get other ISO contacts in the US to make investigations on our behalf. (Emphasis in original)

After being requested to do so by CCSDS Panel 2, SC 13 voted on May 22, 2000 to allow circulation of Red Book 1 as a Draft International Standard (DIS) to all ISO national member bodies. Comments received in response to Red Book 1 – especially those described below from the NEDLIB Project and the NLA – implied substantive changes to the document. SC 13 sent a request to ISO in January 2001 to "reprocess" the DIS, meaning a revised document would be resubmitted to ISO member bodies for another vote. Red Book 1.1 (April 20, 2001), Red Book 1.2 (June 2001), and Red Book 2 (July 2001) were the result of efforts to address the comments received in response to Red Book 1. On October 23, 2001, SC 13 approved the submission of Red Book 2 for ISO vote. There were then a few minor editorial changes to the document before it was then circulated (as the Blue Book) to ISO member bodies for balloting.

4.6.2 Participation and Input in Stage 4

During Stage 4, the OAIS development team received more than 100 external comments on the Red Book, which were each assigned RID numbers. Many of the RIDs were from CCSDS Member Agencies or their subunits (CNES, ESA, GSFC, NASA and NSSDC), but several also came from external actors: Holdsworth of the CEDARS project, International Council for Scientific and Technical Information (ICSTI), NLA, and NEDLIB. It was primarily comments from the external actors that sparked the most significant changes reflected in later versions of the Reference Model.

The beginning of Stage 4 involved additional planning for what would come to be called the Archival Workshop on Ingest, Identification and Certification Standards (AWIICS). On October 13-15, 1999, AWIICS was hosted by NARA, NASA, and ISO TC 20, SC 13. According the minutes from the Ninth International Workshop, AWIICS was "organized with essentially no resources to fund participants. The initial list of invitees was based on attendees at previous workshops." AWIICS tied with the UK Workshop as the third largest workshop in terms of individual participants (49), while it was second only to DADs in terms of different organizational actors represented (37).

All but three of individuals were affiliated with US organizations, with two from the UK and one from Canada. As with other Open Workshops, many of the individual and organizational actors in attendance did not participate in any other ISO Archiving Workshops.

AWIICS came approximately 5 months after the release of Red Book 1. According to the Call for Participation, "This is an opportune time to see what additional standardization efforts may be of interest and to plan for their initiation." The Call for Participation also indicates that the three primary topic areas for the workshop – ingest, identification and certification – were "based on input from the Data Archive Directions (DADs) Workshop and further market interest surveys." Note that this is a smaller subset of the issues laid out in the DADs workshop report. "The goal of this workshop is to initiate development of standards in one or more of these areas through existing national or international standards bodies."

The structure of AWIICS was the following: half-day opening plenary devoted to introductions and background by Sawyer, overviews by the leaders of the three work groups, and one plenary paper presented by Reagan Moore, Associate Director of Data-Intensive Computing at the San Diego Supercomputer Center (SDSC), on "Persistent Archives for Data Collections"; one-day "splinter groups" in each of the three areas; and half-day closing plenary to present "group results and develop plans and schedules for continued standardization efforts." The AWIICS web site identifies seven submitted papers.

At the Ninth International Workshop on November 9-10, 1999, discussion of the Archiving Work Package began with concerns about low participation in the review process. "[The] CCSDS review period has ended. There have been very few RIDS [Review Item Disposition – the form used for submission of official comments]. ISO review started in August – finishes in December. We need to promote the ISO review." Panel 2 decided to request of the Management Council that it extend the CCSDS review to January 2000, in order for it to be "coterminous with the ISO review." Another action item was for all members to "make personal contact with potential ISO reviewers to request comments." Sawyer indicated that NASA would "invite people to submit general comments (other than RIDS)." The Panel 2 discussion was then devoted primarily to two items: (1) the review of RIDs that the National Archives and Records Administration submitted on October 26, 1999, and (2) outcomes from the AWIICS workshop.

On January 30-31, 2000, ICSTI and ICSU (International Council for Science) Press sponsored a workshop at UNESCO in Paris on "Digital Archiving: Bringing Issues and Stakeholders Together." The workshop was a follow-on activity to the April 1999 ICSTI report by Hodge and Carroll discussed in my summary of Stage 3 activities above. The OAIS was a major topic of discussion at the January 2000 ICSTI/ICSU workshop, and Giaretta, Chair of CCSDS Panel 2, served on one of the panels. The workshop was an important opportunity to publicize the Reference Model and solicit input among a set of actors who were generally not otherwise involved in the OAIS development process. Of the 54 ICSTI/ICSU workshop participants, three would later attend one or more ISO Archiving Workshops, though Giaretta was the only participant in the ICSTI/ICSU workshop to have taken part in any earlier ISO Archiving Workshops. During this same time, ICSTI was soliciting input on the OAIS through its member ICSTI member organizations. Hodge collected the comments and the submitted them to the OAIS editorial team (Dacombe, 2002) in order to be addressed as RIDs (44 total).

A few months after he attended the AWIICS Workshop, Brian Lavoie, Associate Research Scientist at the OCLC Office of Research, published a piece called “Meeting the challenges of digital preservation: The OAIS reference model” in the January/February 2000 issue of *OCLC Newsletter*. This clear and concise summary (not quite five pages long) would be cited frequently in the literature discussing the OAIS, often even instead of citing the Reference Model itself. Although the only ISO Archiving Workshop Lavoie attended was AWIICS, his writing about the OAIS appears to have served as an influential vector of diffusion. The core team members also sometimes cited it in presentations to external groups, and it was referenced in the minutes of the Tenth International Workshop in May.

At the Tenth International Workshop on May 12-15, 2000, there was discussion of activities to review the Reference Model in countries other than the United States. In relation to Francophone review of the Reference Model, the minutes indicate, “CNES produced the French translation of the OAIS document. ISO have [sic] this translation. CNES have distributed it to French companies to get RIDS.” Yoshio Inoue of Japan’s National Space Development Agency (NASDA)[38] indicated the SC13 National committee of Japan had been founded to discuss and vote on Draft International Specifications from TC20/SC13. Inoue reported, “At a meeting of this committee held at the end [of] last year, I explained the outline of the OAIS reference model and distributed the material” to the members.

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[38] On October 1, 2003, NASDA merged with two other entities to become the Japan Aerospace Exploration Agency (JAXA).

The Tenth International Workshop also included a discussion of a paper by Sawyer, Reich, Giaretta, and Peccia that aims to “identify a set of functions that are typically associated with the concepts of a mission archive, and to describe some implications of the OAIS reference model for these functions.” The authors had developed the paper for the June 2000 SpaceOps meeting. Participants in the Tenth International Workshop considered what aspects of mission archives may be particular to each mission and what “common areas could/should be standardized.” Reich proposed “the development of Use Cases illustrating the major workflows and lifecycle issues in mission archives, as the highest priority. This is a more formalized description of scenarios than the more free-form descriptions provided in the past.” Citing a RID from CNES about the definition of Content Information, the minutes indicate, “It is clear that PDI [Preservation Description Information] is still an issue.”

The CNES and the BnF organized two meetings related to the OAIS (“Report on the OAIS meetings,” n.d.). The first, on May 30, was “to exchange opinions and experience in the archiving field and concrete application of the OAIS Reference Model” and involved individuals from CNES, BNF and “a Dutch representative of the NEDLIB project.” The second meeting, which took place on June 15, involved a variety of organizations and presentations by CNES and BNF personnel. Participants expressed interest in having a forum to continue discussions about digital archiving issues, and someone created an email list for this purpose.

In June 2000, the KB issued a document entitled “NEDLIB Contribution to the Review of OAIS.” The documented reports to the CCSDS (through the CNES as a CCSDS member agency) “how project NEDLIB has applied, scoped and extended this

Reference Model to the needs of digital deposit libraries." The June 2000 KB document contends that the OAIS Reference Model "provides some perspectives on the issues of information preservation using digital migration across media and across new formats or representations, but it is not clear which processes are needed and which functionality is required." Consistent with a report by Jeff Rothenberg related to emulation, which he wrote for the KB in association with the NEDLIB project in April 2000, the June 2000 KB document states that the OAIS does not specify one digital preservation strategy, but it "implicitly accepts data migration, i.e. 'transformation' of digital content, as the preferred strategy," and "it is not clear where transformation processes take place in OAIS."

> What NEDLIB found missing in the OAIS Model was a conceptual entity symbolising the preservation processes required of an OAIS, whatever the preservation strategies followed. Therefore NEDLIB has added in its DSEP [Deposit System for Electronic Publications] model a Preservation entity that manages the preservation processes required of a DSEP. Although it is recognised that the preservation function affects all DSEP processes, NEDLIB has added this separate preservation entity to make this function more visible and more explicit in the model. Much in the same way as metadata processing affects all DSEP functions, still, OAIS has defined a separate Data-Management entity to visualise the metadata processing function.

When reporting on attempts to map the OAIS to the DSEP, the June 2000 KB document indicates, "OAIS functionality is situated partly outside and partly inside the actual limits of a DSEP." A high-level process model for the DSEP (see Figure 4) indicates how the NEDLIB project extended the OAIS functional model to meet its needs.

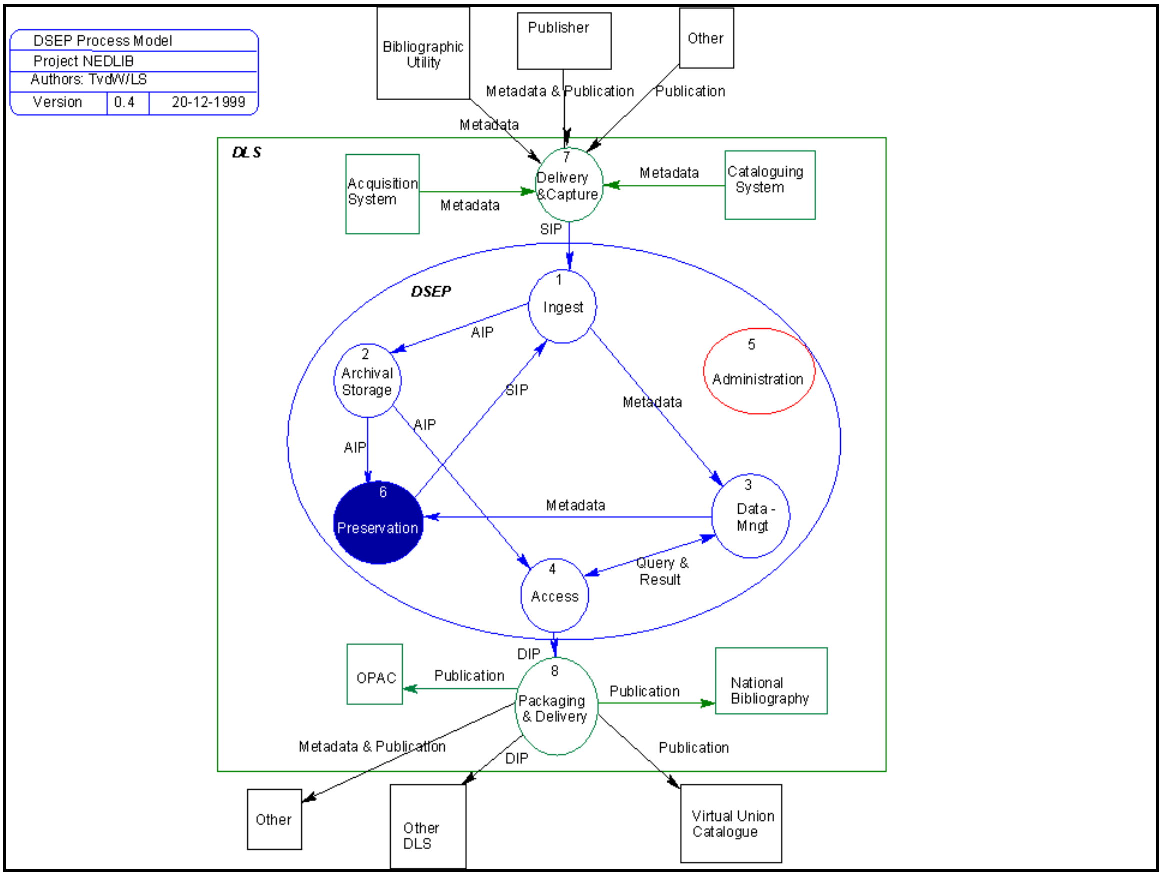

Figure 4 - DSEP Process Model from the NEDLIB Project
[Source: "NEDLIB Contribution to the Review of the OAIS," June 2000]

On June 6, 2000, the National Library of Australia also issued a document commenting on the OAIS. The document indicates that the NLA found the OAIS to be an "extremely valuable framework for the development of requirements for our digital archive," which had "reached a high level of maturity." The NLA provided several specific suggestions for clarification of the Reference Model, but its primary suggestion was to add a preservation function, making direct reference to work by the NEDLIB project. The NLA noted that the NEDLIB DSEP had added several extensions to the OAIS, which might be specific to "deposit libraries building selective archives of electronic publications" and thus outside the scope of the OAIS. "However, we see the preservation function is a core responsibility of an OAIS." The NLA states that a Preservation function should be "separate from Archival Storage to support Digital Migrations that change the Content Information and therefore create a new Archival Information Package."

Both the Seventeenth US Workshop on July 19-20, 2000 and the Thirteenth International Workshop on October 22-24, 2001 were primarily devoted to discussion of external comments that commented upon the Reference Model. These included "CEDARS input to OAIS" by David Holdsworth; "Comments from the National Library of Australia" (June 6, 2000); "NEDLIB Contribution to the Review of OAIS" (June 2000); "An Experiment in Using Emulation to Preserve Digital Publications" (April 2000); RIDs from NARA (October 1999), CNES, ESA and NASA (September 1999).

The Nineteenth US Workshop on February 20-23, 2001 did not quite fit the mold of short US Workshops as small working meetings of the core development team. Lasting three and a half days, this was the longest of the US Workshops, which were usually only two days long. It was the largest (with 15 individual participants) and most organizationally diverse (with 14 organizational actors) US Workshop since the Third US Workshop almost five years earlier. It also had the most first-time and one-time individual participants of all US Workshops, besides the First US Workshop. For most of the non-core-team participants in this meeting, their entrée into the ISO Archiving effort had been through AWIICS, about 18 months earlier. The agenda was also unusual in including 6 presentations related to external activities – including the InterPARES project and activities at the ICSTI, RLG and U.S. Department of Agriculture (USDA) – rather than focusing exclusively on the development of the Reference Model and other Archiving Work Package standards activities.

An invitational seminar entitled "Digital Curation: Digital Archives, Libraries, and E-Science," sponsored by the Digital Preservation Coalition and British National Space Centre (BNSC), took place on October 19 at the headquarters of the Institution of Professionals, Managers and Specialists (IPMS).[39] According to the workshop web site, "The seminar aimed to raise the profile of the Open Archival Information System Reference Model (OAIS) standard in the UK and share practical experience of digital curation in the digital library sector, archives, and e-sciences." The majority of participants were from institutions in the UK, with a few from the US. Much of the discussion related to access provision, data grids and infrastructure to support research, though there were several specific conversations about the OAIS, including its "potential value and limitations."

The Federal Library and Information Center Committee (FLICC) and CENDI (an inter-agency group of senior federal scientific and technical information (STI) managers) held a joint symposium on December 11 at the Library of Congress entitled "Managing and Preserving Electronic Resources: The OAIS Reference Model." This one-day event involved a series of plenary presentations and then a panel. Speakers and panelists included Sawyer and Reich, but also included individuals from RLG, NARA, Library of Congress, GSFC, National Agricultural Library (NAL), U.S. Government Printing Office (GPO), OCLC, USGS, National Library of Medicine (NLM), and ICSTI. Of the ten

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[39] IPMS was a labor union. On November 1, 2001, it merged with the Engineers and Mangers' Association (EMA) to form Prospect, a union aiming to represent professionals, managers and specialists in the public and private sectors.

speakers and panelists, five had also participated in ISO Archiving Workshops (in all cases, some combination of DADs, AWIICS or Nineteenth US Workshop).

4.6.3 Content of the Reference Model in Stage 4

There were five versions of the Reference Model available during Stage 4: Red Book 1 in May 1999; Red Book 1.1 on April 20, 2001; Red Book 1.2 in June 2001; Red Book 2 in July 2001; and finally the Blue Book in January 2002.

Released the month after White Book 5, Red Book 1 is the last version of the Reference Model to contain a substantial set of changes throughout the document. Red Book 1 reflects 4 new definitions, 3 dropped definitions and 19 definition changes. It also includes a new detailed composite figure of all functional entities. The main functional model figure had been present in various forms since Version 1, and many figures developed since then provided more detailed views of the parts of the functional model. By Stage 4, the Reference Model contained a large number of figures (39 in Red Book 1 and 38 thereafter), which were often inter-related. This raised two potential problems: first, readers might understand the big picture in the main functional model and each of the more detailed figures, but still not have a clear idea of how they fit together; second, those making revisions to entity-specific figures might make changes that conflict with changes in other entity-specific figures. Red Book 1 was the first version to address these issues by providing figure “F-1: Composite of Functional Entities” at the end of the document (in Annex F). This figure is very detailed, containing 39 distinct boxes and 53 lines indicating relationships between them, which could give the false impression that it is intended as a specification to be implemented directly. The text accompanying Figure F-1 warns readers “not to assume that this is a recommended design or implementation. It should be useful for discussing concepts and comparing systems."

As suggested by the version number, Red Book 1.1 largely reflects revisions and elaboration of existing content, rather than introducing significant new concepts; many sections have seen no change or only minor copyediting. Red Book 1.1 does reflect the last major set of changes to the definitions section, with 11 new defined terms and 14 changes to existing definitions. Three relatively localized but important sets of changes relate to Preservation Planning, emulation, and interchange between archives. First, the introduction of Preservation Planning as a new entity in the functional model has brought several associated changes to Red Book 1.1. Given the numerous dependencies now built into the well-developed Reference Model, the introduction of Preservation Planning as a completely new entity has resulted in several changes to both the text and figures. The only new figure in Red Book 1.1 is called "Functions of Preservation Planning." Of the eight changed figures, three are changed so that they can now include Preservation Planning. Second, Red Book 1.1 reflects some changes in response to suggestions that the Reference Model be more inclusive of emulation as a potential digital preservation strategy. In Red Book 1.1, the section on "Information Definition" includes a new paragraph stating that some organizations will "require that the look and feel of the original presentation of the information be preserved. This type of preservation requirement may necessitate that the software programs and interfaces used to access the data be preserved." The new paragraph, which also discusses emulation, remains unchanged through the Blue Book. In Red Book 1.1, the section on Representation Networks is substantially revised, as is he section on Access Service Preservation, including lengthy discussions of look and feel, and emulation. The section on Representation Networks is also substantially revised in Red Book 1.1. An important question related to digital preservation strategies is whether or not a new, transformed copy of an AIP should be treated as a replacement for the original. Reflecting a set of distinctions introduced earlier between versions, editions and derivations, Red Book 1.1 introduces definitions for Derived AIP, Version and Edition. Finally, it provides some additional contributions related to interchange and interoperability between multiple archives. Of the 11 new defined terms in Red Book 1.1, four of them relate to the discussion of interaction and interoperability between archives: Co-operating Archives, Federated Archives, Global Community, and Local Community.

Red Book 1.2 reflects agreements at the Twelfth International Workshop and is somewhat shorter than Red Book 1.1. Red Book 1.2 has only one new term in the definitions section, which is the result of replacing Rendering Software with Representation Rendering Software and keeping the exact same definition.

Red Book 2 remains substantially similar to Red Book 1.2. It contains the same list of definitions as Red Book 1.2 and reflects only one slight non-substantive wording change to a single definition. Most of the text is not changed, and the changes that have been made are largely stylistic (e.g. spelling out of acronyms, capitalization, adding commas, hyphenation of compound phrases) and some revisions to external references, primarily other CCSDS standards. Besides now carrying the official endorsement of the CCSDS, there also are very few changes between Red Book 2 and the Blue Book. It is almost identical in length.

4.7 Stage 5 - ISO Standardization (January 2, 2002 – February 24, 2003)

From a formal, procedural perspective, Stage 5 was the most essential part of the OAIS development process. This is when ISO national member bodies had the opportunity to decide officially whether or not the Reference Model would receive ISO endorsement as an International Standard. In fact, apart from the act of formally legitimizing the OAIS as an International Standard, there was very little activity during Stage 5 that contributed substantially to the structuration of the OAIS. The ISO balloting process was nominally a signal of national member body commitment to the standard, but it actually served as the capstone to a process of review and commitment by a much broader set of actors that spanned almost eight years preceding the official vote. Stage 5 is important to flag as a separate part of the OAIS development chronology precisely because (1) it involved a set of actors and processes that were markedly different from those involved in the first four stages and (2) contrary to what one might have assumed based on the SDO decision making procedures, it was generally not "where the action was," in terms of influence and negotiation over the contents, scope and public framing of the Reference Model.

The start date of the ISO balloting process, which involved ISO national member bodies, was January 24, 2002 and the closing date was April 5, 2002. An ISO national member body "is the national body most representative of standardization in its country." There is only one ISO member body for each nation, which represents it in all ISO votes. These are not the same organizational actors as the CCSDS Member Agencies. For example, the ISO member body voting on behalf of France was the Association Française de Normalisation (AFNOR), rather than CNES, and voting on behalf of the UK was the

British Standards Institution (BSI) rather than BNSC. There were eight affirmative votes (Canada, China, France, Germany, Japan, Russian Federation, Ukraine, United Kingdom), no negative votes, and two abstentions (Austria and Sweden). The national member bodies representing Italy and the U.S. – Ente Nazionale Italiano di Unificazione (UNI) and ANSI, respectively – did not register votes at all. In the case of the U.S., this appears to be because SAE, which was then the Secretariat responsible for TC 20 activities within ANSI, failed to distribute the DIS to the chair of the appropriate ANSI subcommittee.[40] Nonetheless, the 8-0 voting result meant that the DIS did not require any further revisions and did not need to go through an additional round of ISO voting as a Final Draft International Standard (FDIS). The chair of SC 13 formally reported the results of voting on the Reference Model to ISO on August 20, 2002. Approximately six months later, on Feb 24, 2003, the Reference Model was finally published by ISO as an International Standard (ISO 14721:2003).

4.8 Conclusion

This chapter has provided a detailed narrative account of the OAIS development process. What began as a NWI proposal for a narrowly construed set of formatting standards for the archiving of space data became a high-level conceptual document, reflecting contributions and buy-in of a wide range of actors, including many outside of the space data arena. In order to understand the OAIS development process, it is important to recognize two critical facts: (1) the Reference Model was developed and approved within the existing CCSDS standardization structures, and (2) development of the OAIS was markedly different from the previous standards development efforts of the

[40] Personal correspondence with Linda Kezer, NASA Headquarters, September 15, 2005.

CCSDS by being both broader in scope and inclusive of a more diverse set of actors. In this chapter, I have identified five stages. The points of demarcation between the stages align very closely with the milestones in the formal CCSDS process (reflecting fact 1). Because the fate and status of the Reference Model was so closely aligned with the CCSDS versioning and endorsement system, the stages also correspond to different phases in the life of both the Reference Model and the network of actors associated with its development. However, such an account does not tell the whole story. A fuller understanding and appreciation of the Reference Model's unique trajectory (fact 2) requires an elaboration of the trends and patterns that cut across the details of narrative. That is the goal of Chapter 5.

CHAPTER 5 – GENERAL TRENDS AND PATTERNS IN THE OAIS DEVELOPMENT PROCESS

We can lick gravity, but sometimes the paperwork is overwhelming.
- Attributed to Wernher von Braun, 1958

Chapter 4 provided a relatively detailed narrative account of the OAIS development process based on a five-stage chronological structure. This chapter discusses higher-level trends and patterns that emerge from that narrative account. As in Chapter 4, I use three general categories to present these findings: work structure and process; participation and input; and content of the Reference Model. I then also summarize the major issues discussed by participants in the process.

5.1 Work Structure and Process

Development of the OAIS took place within the formal structure of the CCSDS (see Appendix 9). The OAIS development effort generated 20 total versions of the document: 8 informal drafts (Concept Paper phase), 7 White Books, 4 Red Books and 1 Blue Book.

There were 36 ISO Archiving workshops between the initiation of the Digital Archiving Work Package and the approval of it as a Blue Book in January 2002. I have identified three general categories: 18 US Workshops - working meetings, generally involving the core development team; 13 International Workshops – taking place within the CCSDS semi-annual Panel 2 meeting structure and devoted primarily to formal review of the Reference Model; and 5 Open Workshops - organized specifically for discussion, review and input from a much wider set of actors

This work structure is not typical for CCSDS standards efforts. Historically, CCSDS Recommendations have been documents developed chiefly by and for national space agencies. Each Member Agency is ultimately responsible for representing the interests of its country, e.g. CNES representing France, BNSC representing the UK, NASA representing the U.S. By attempting to foster input from actors outside of the CCSDS, both the US and Open Workshops (and the wide dissemination of documents associated with those events) break the typical CCSDS mold. During my interviews, several participants commented that the OAIS was quite different from previous CCSDS standards efforts by being at such a high level of abstraction and attempting to address considerations outside of the earth science and space science arenas. Several participants also pointed out that the diversity of participants was unusual for a CCSDS standard. One individual stated, “I think the important thing about the process is that it was a change for CCSDS to be so open to outside groups.” (I2)

After deciding that the development of the Reference Model should involve this unprecedented (for the CCSDS) series of US workshops with representatives from outside the usual set of players, the leaders of the Reference Model effort investigated the possibility of passing responsibilities for the US workshops to another organization with more experience in soliciting and incorporating input from various US organizations. The leaders of the Reference Model effort contacted the National Information Standards Organization (NISO) about playing this role, but NISO representatives did not express interest in leading the effort. According to one of the core OAIS team members:

> So in the end, we just said, ‘Well, shoot. We know kind of how to do standards. We’re just going to form our own process. Just work it.’ So what we are going to do is we are going to use the Web. We are going to publicize things. We are going to advertise and hold periodic meetings. And just get people together, and we’ll just start working it. (I4)

Garrett, for example, developed and maintained an extensive collection of Workshop and other related documents on the Web. This online presence played a pivotal role in the enrollment of actors from the environment, including members of the NEDLIB project, who first learned about the Reference Model through the Web.

5.2 Participation and Input

Although this activity was placed within the CCSDS, a standards development organization (SDO) with a relatively focused mandate related to space and terrestrial data, the process soon involved actors from a diverse set of institutions and professions. Development of the OAIS served as locus of two interrelated processes: (1) the social definition of an emerging area of work, and (2) the technical definition of a standard to describe, coordinate and guide future standardization of that work.

There were a large number of total participants, but the majority attended only one Workshop. The development process was based on a core team of individuals who met regularly and carried out writing, editing and review tasks; and a more peripheral set of actors whose contributions were generally through one of the five Open Workshops or through the contribution of written comments on the Reference Model.

By some measures, the participants in the ISO Archiving Workshops are a fairly homogeneous group. As one might expect, more than half (57%) of the 308 individuals who participated in at least one ISO Archiving Workshop were from space or earth science agencies; constituent organizations of space or earth science agencies; or contractors with space or earth science agencies.[41] More specifically, close to one quarter (23%) of all participants were affiliated with NASA – which served as the administrative home of the standards effort – or one of its contractors. If one considers only the 115 individuals who participated in at least one US or International Workshop (excluding those who only took part in the more organizationally diverse Open Workshops), an even larger portion of the individuals had space/earth science agency (74%) and NASA (39%) affiliations. Of the 291 individuals whose gender I could confidently identify, 80% (232) are male and 20% (59) are female. Many of the terms, examples, and past experiences that participants shared in the discussions were from work with terrestrial and space data. Participation of individuals associated with libraries in US and international workshops was very limited. Until AWIICS (four years after the first Workshop), Ambacher from NARA was the only institutional records archivist to participate in Workshops, and he was the only individual from NARA to attend more than one Workshop.

Private sector participation in the OAIS development process was also surprisingly limited. Of the 20 organizational actors that sent individuals to seven or more Workshops, only five were from the private sector (Computer Sciences Corporation; Hughes STX, which then became Raytheon STX; Lockheed-Martin; and SGT). For all five of the companies, the individuals they sent were working as contractors for NASA. All of the individuals from the private sector whom I was able to

[41] The UK space agency, BNSC, has 11 partner members, including the UK Ministry of Defence. However, I have not counted component elements of the Ministry of Defence as constituent space or earth science agencies.

interview indicated that their contracts with NASA paid for them to do standards development work.

However, from the very beginning, the process did involve some participants who were not direct stakeholders in the CCSDS. The word “Open” in the acronym OAIS – meant to indicate that the standard was “developed in open forums” – was a defining feature of its evolution. One consequence was less predictability than might have been the case in a more clearly circumscribed and “closed” effort (Hughes, 1983, p.6).

The openness of the OAIS development process took a variety of forms. For example, Ambacher from NARA, not a traditional stakeholder in CCSDS activities, was a very active participant, who began attending with the first US Workshop and began serving as a host of the US Workshops starting with the third. Some specific workshops also broke from the regular flow of small working group meetings and included a large set of actors from many organizations and professional fields. Sawyer, the primary leader of the OAIS development process, indicated early and continued to reiterate that the process should be open and inclusive, in order to get sufficient input and buy-in. “[The] ultimate success of [the] OAIS Reference Model effort depends on obtaining adequate review and comment” (Sawyer, 1999). The openness of the OAIS development process generally did not take the form of diversity of the core participants, but instead came through their review of external literature, solicitation of public comments, presentations to many audiences, and holding of open meetings to get input from peripheral players.

There were a large number of total individuals who participated in ISO Archiving Workshops (306), but the majority (244 or 79%) attended only one Workshop (see Figure

21). The participation frequencies of organizational actors follows a similar pattern (see Figures 23 and 24) Consistent with the three categories of Workshops discussed above, after the first US Workshop, participation patterns settled into a notable pattern: a small set of very consistent participants at US Workshops; a slightly larger and fairly stable set of participants at International Workshops; and a much larger, more diverse set of peripheral participants at Open Workshops (see Figures 22 and 25).

The set of consistent workshop participants was largely affiliated with space agencies, especially NASA.[42] Squibb of the JPL wrote the original proposals for the development of a set of data archiving standards within the ISO, and the leader of the effort was Sawyer of NASA. Of the 14 most frequent attendees, 12 were affiliated with space agencies, and 7 were affiliated with NASA. The bulk of the work on writing and editing of the Reference Model was carried out by a core US team. There were also a small set of individuals who regularly took part in the International Workshops and thus provided consistent oversight, review and administrative guidance through the standardization process.

A set of legitimate peripheral participants (Lave and Wenger, 1991) played an essential part in the OAIS development process. These individuals came from a more diverse set of institutional contexts than did the consistent workshop participants. They provided a reality check on applicability of the Reference Model beyond space data centers, and helped to enact "weak ties" to the external social networks in which they were embedded (Granovetter, 1973). Legitimate peripheral participants also provided some fundamental contributions to the document. For example, Preservation Planning

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[42] For further discussion of the main organizational actors, see also Appendix 6 – Major Organizational Actors in the OAIS Development Process.

was introduced as a new entity relatively late in the process (Red Book 1.1 on April 20, 2001), after suggestions from the NEDLIB project and National Library of Australia.

5.3 Content of the Reference Model

In its Blue Book form, the Reference Model is a 148-page document, composed of six sections and six annexes. Section 1 frames the content to follow, by providing discussions of purpose, scope, applicability, definitions, rationale, and conformance requirements. It also situates the document in a larger context by including a "road map for development of related standards." Section 2 lays out several core concepts that are then modeled in more detail in Section 4. These include archive; information (as distinct from data); interfaces between an archive, Producers, Consumers and Management; and Information Package and its subtypes: Submission Information Package (SIP), Archival Information Package (AIP) and Dissemination Package (DIP). Section 3 discusses the responsibilities of an OAIS and "some examples of mechanisms to discharge these responsibilities." Section 4 presents a "more detailed model view" of the concepts previously laid out in the document. The section includes a functional model (including a high-level view, unpacking of each entity and data flows between the entities) and an information model, which provides a hierarchical set of views and explanations for what logical elements should be stored and managed in association with a data object to ensure that the data objects remains accessible and understandable to an expected population of users (Designated Community) over the long term. Section 4 also provides an account of the "transformations, both logical and physical, of the Information Package and its associated objects as they follow a lifecycle from the Producer to the OAIS, and from the OAIS to the Consumer." Section 5 provides some discussion – intended to be implementation agnostic – of technical issues and strategies that an archive can potentially use to address changes in underlying hardware, software, formats and access services. Section 6 discusses potential arrangements between multiple archives. The annexes that follow Section 6 are not considered part of the Reference Model's normative content but are instead "provided for the convenience of the reader." The annexes include a set of five "scenarios" that use OAIS terminology and concepts to describe specific existing archives; explanations of how the Reference Model relates to other standards and projects; a brief Unified Modeling Language (UML) tutorial; list of references; a layered model of how software could be used to support Representation Information; and a fairly complicated "composite diagram" that presents in one place the detailed interfaces between each of the entities in the functional model.

The definitions section of the Reference Model was often an important focal point of writing, and it has served as one of the fundamental components of the document. It generally served as a place to codify existing language, rather than introduce entirely new terms. Of all the instances of new definitions in the section, 70% were terms that had been used somewhere else in the text of the previous version of the Reference Model. The set of definitions underwent dramatic change throughout the process of developing the Reference Model. There are 156 distinct terms that were presented in the definitions section of at least one version of the reference model, but only 79 (about 51%) of that total were included in the definitions section of the Blue Book. The definitions that appear in the Blue Book are generally those that have withstood ongoing scrutiny and review over several versions of the Reference Model.

A considerable amount of attention throughout the OAIS development process was devoted to details of the figures contained in the Reference Model. The figures helped to focus discussion, clarify distinctions and identify areas in need of further development. They also served as valuable tools in abstraction efforts, by allowing a given figure to present only a small set of characteristics about the entities and interfaces at a given level of abstraction, while allowing an interested reader to drill down into more detail by viewing other figures that presented entities and relationships at finer levels of abstraction. The Blue Book contains 38 figures, which allow the Reference Model to present a complex picture through a set of relatively simple and discrete views. "The trick in using OMT [Object Modeling Technique] effectively is to determine what to hide and what to show in an effort to help the reader grasp the most important concepts." (Sawyer, 1997)

5.3.1 Content Adopted from Other Documents

As a reference model, the OAIS was intended to serve as (among other things) the basis for the development of more specific standards. This is consistent with Cargill's standardization planning model. However, the OAIS document also contains many elements borrowed and adapted from external documents. Many of the external documents that served as sources for OAIS content are more specific standards or guidance documents. This suggests an extension to Cargill's model (see Figure 5 below), indicating that not only can reference models serve as the basis for more domain-specific standards, but more domain-specific documents can also serve as at least part of the basis for the development of a reference model.

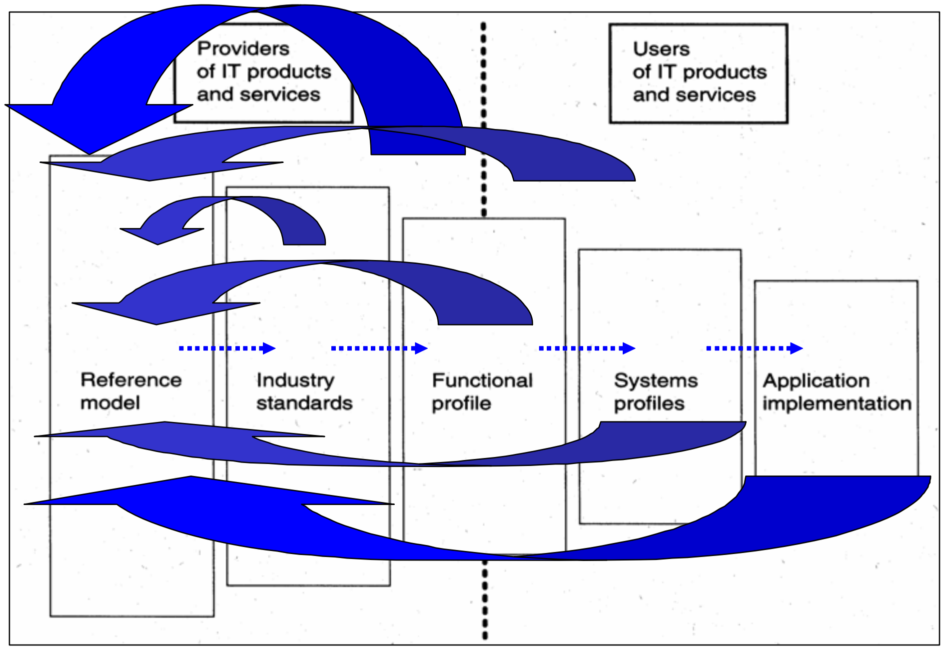

Figure 5 - Extension of Cargill's Standardization Planning Model

Much of the literature about reference models explains how standards development within an industry can progress from the left side to the right side of Figure 5.[43] First, a reference model is developed to set the conceptual and strategic framework within a given arena. Then industry standards are developed, based upon and further specifying parts of the reference model. In turn, other types of standards can be developed, to further specify technical components or processes. Each step from left to right involves additional assumptions, constraints and "subsetting" of features, in order to meet the needs of a more specific context or set of users (Cargill, 1989, p.52). The large arrows

[43] Cargill acknowledges that the chronology of standardization will not always be a strictly linear progression from left to right in his planning model. However, he and many other authors do generally emphasize the role that reference models can play in serving as the basis for a succession of more specific standards.

pointing from right to left represent one of the lessons from my study. Development of the OAIS involved a significant amount of borrowing from existing guidance documents, many of which had been designed for more specific organizational or technological contexts, e.g. the *PDS Data Preparation Workbook* applies to the submission of peer-reviewed scientific data sets into the Planetary Data System. In such cases, one of the primary challenge for the developers of the OAIS was not “drilling down” (i.e. applying additional constraints or parameters to a higher-level standard), but was instead “abstracting up” (i.e. reframing lower-level concepts and models in ways that made them applicable to a much broader set of actors and resources).

5.3.2 Stabilization of Reference Model Content

The OAIS development process included significant early negotiation and revisions to the Reference Model document. Later changes were less frequent and more limited in scope (see Figure 6). Documents from the OAIS effort suggest an increasing commitment to content of the Reference Model and reluctance to make dramatic changes.

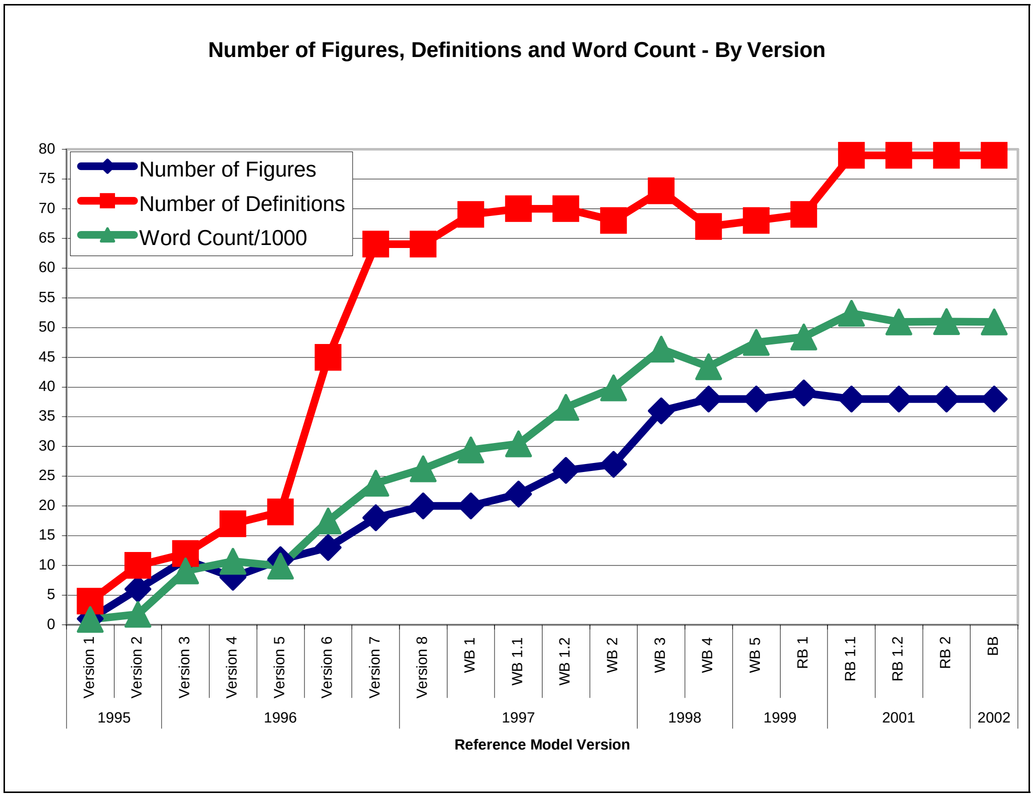

Figure 6 - Number of Figures, Definitions and Word Count - By Version

For example, in April 1998, just a few days before the Reference Model reached White Book status, several members of the development team proposed combining two of the main entities of the functional model (Dissemination and Access) into a single entity. They felt compelled to offer a detailed rationale. “We do not make this proposal lightly as we are reluctant to make this level of change at this stage of the development.” A few months later, at the Ninth US Workshop (September 30 – October 1), there was a substantial conversation about whether packaging information should be considered inside or outside the package itself. This is an issue that gets at some fundamental aspects of the information model. The minutes from the Workshop state: “The question was asked, ‘THIS IS BRAND NEW STUFF – ARE WE ALLOWED TO INTRODUCE NEW STUFF?’” (emphasis in original) Some participants, however, still indicated willingness to alter basic terminology and try new approaches. The minutes later indicate, “It was agreed to try PI [Packaging Information] outside the IP [Information Package], but with reluctance by some overcome by the need to allow the review to proceed.”

5.4 Major Issues Discussed by Participants

As discussed in Chapter 2, a model always “deals with its subject matter *at some particular level of abstraction*, paying attention to certain details, throwing away others, grouping together similar aspects into common categories” in ways that necessarily do “a certain amount of violence to its subject matter” (Smith, 1996, p.815-816). An important aspect of developing a model is deciding what details to leave out. For a reference model, which is intended to be “implementation-independent” and the basis for the development of more specific standards, the level of abstraction is particularly high. Other important design decisions relate to the particular language of a reference model: what terms to define, what terms to take for granted as understood by the reader and what terms to leave out entirely.

5.4.1 Scope of the Reference Model

One set of issues that emerged periodically throughout the OAIS development process related to what types of data fall within the scope of the Reference Model. The New Work Item defines the scope in terms of “digital data obtained from, or used in conjunction with, space missions,” and many documents associated with the development effort indicate a focus on “information obtained from observations of the terrestrial and space environments.” However, the leaders of the OAIS development effort also stated frequently that they hoped the Reference Model could be inclusive of many more types of information. The tension between the CCSDS formal mandate and a more inclusive scope for the Reference Model was a defining characteristic of its development and content. Participants discussed whether or not the Reference Model should be framed exclusively in terms of digital data or whether it should also include physical/analog data. The most vocal advocacy for including physical data within the Reference Model came from actors within the Life Sciences Data Archive (LSDA), who had physical specimens in their collections. The Blue Book states:

> In this reference model there is a particular focus on digital information, both as the primary forms of information held and as supporting information for both digitally and physically archived materials. Therefore, the model accommodates information that is inherently non-digital (e.g., a physical sample), but the modeling and preservation of such information is not addressed in detail.

While there are many aspects of the Reference Model that are not directly relevant to physical/analog data (e.g. Digital Migration, Representation Information), the basic elements of both the functional and information model are explicitly inclusive of physical objects. A related issue was whether the Reference Model should address only "non-reproducible" data or also address data that could be reproduced. The final version is inclusive of both.

Another set of issues regarding the scope of the Reference Model relate to which functions and services should be considered parts of an archival information system, thus necessitating explicit representation and discussion, as opposed to functions and services that are considered part of the supporting infrastructure. One set of distinctions introduced into the Reference Model, and considerably revised over time, is between Archival Services, on the one hand, and Generic Services or Common Services, on the other. Participants also had to decide the role and placement of Administration and Management. Another discussion related to whether or not "value-added" activities such as "processing," transformation and transactions performed on preserved digital objects should be considered part of an OAIS and whether there should be a processing/transformation/production entity or it should be considered part of existing entities. There was also considerable discussion and editorial attention related to the role of external archives in the Reference Model, e.g. federation and archives acting as Producers/Consumers to other archives.

5.4.2 Normative Status of the Reference Model

Another ongoing set of issues relate to the ways and degree to which the Reference Model should serve as a normative document. At a very low level, discussions addressed issues of language, such as the degree to which the Reference Model should use prescriptive words like "must" or "shall." At a higher level, there was attention to the part of the text indicating what it means to conform to the Reference Model. Participants also considered whether the Reference Model or parts of it (e.g. the archives scenarios) should be published as a Green Book (informative, non-normative report) rather than a Blue Book (CCSDS Recommendation to which Member Agencies' internal standards are expected to conform).

5.4.3 Differences Between Types of Archives

Differences between types of archival environments posed an ongoing challenge in the development of the Reference Model, which is intended to apply to a variety of institutions and collections. Most of the chief actors were associated with space agencies, space science data centers, or earth science data centers. Even among this set of actors, however, there were often striking differences in terminology, experiences and practices. Among the total set of actors involved in the OAIS development and review process, there was an even wider variety of vocabularies, experiences and practices. ISO Archiving Workshop documents and versions of the Reference Model reveal differences in perspective on the relative importance of copyright and other legal restrictions on access; automated as opposed to manual execution of services and functions; degree of detail with which the custodian of digital information must understand its Representation Information; how much and what type of knowledge can be expected of Producers and Consumers; types and level of archive intervention in Producer activities; where to draw the boundary between data or information objects and their associated supporting data; what kinds and how much metadata are required; and how data are aggregated and what those aggregations are called.

The discussion within the Reference Model of copyright and other legal restrictions is evidence of the tension between the relatively inclusive OAIS development process, on the one hand, and the CCSDS orientation toward earth and space science data, on the other. Copyright is not generally a primary concern of those responsible for scientific data generated with government funds, but it is a serious concern for those responsible for collections of published material. Version 7 introduced a very short discussion of copyright considerations. This portion of the Reference Model was revised several times, though it ultimately provided very little detail. Despite this issue's relevance to institutions responsible for published materials,[44] it does not appear to have been a priority to many of the active participants in the OAIS development process. Fairly late in the process, at the Ninth International Workshop, Panel 2 did accept recommendations from NARA to expand the "copyright implications" paragraph to include other intellectual property and legal restrictions, and addition of wording that reflected NARA's concerns with deeds of gift and other legal instruments that can place encumbrances on materials.

One mechanism through which the developers of the Reference Model attempted to address its applicability to a diverse set of institutional contexts was the "archives scenarios." These informative (non-normative) parts of the document attempted to map the terms and concepts of the Reference Model to specific collections or repositories. Some issues related to the scenarios were what to include in them, where in the document they should be located, and what sorts of repositories needed to be represented.

Another potential way to address the diversity of archives is through a formal taxonomy, which could identify the similarities and differences between archives. The New Work Item document, which lays out the original scope and purpose of the ISO Archiving Standards effort indicates a plan to define, not just a reference model, but also "service categories," which "will include levels of user expertise needed to understand archive, content, number of users who can be simultaneously served, and type of data and metadata services." This was generally interpreted by leaders of the OAIS development

[44] At the DADs Workshop, Working Group 1 (which included a large contingent of library and archives representatives and relatively little representation from actors responsible for space science data) concluded, "An identified gap in the model is the lack of discussion of rights management issues dealing with copyright, intellectual property, proprietary data, and the like." Three of the comments that ICSTI submitted in response to Red Book 1 also related to elaboration of intellectual property issues.

effort to mean that they should produce a taxonomy of archives, to be included within the text of the Reference Model. While each of the "service category" issues laid out in the New Work Item are discussed separately in various parts of the final version of the Reference Model, an effort to develop a classification system of archives and archives services was never fully developed and was eventually dropped from the document. One label for a particular category of archives that did become well-established within both the development discussions and versions of the Reference Model is "traditional archives." The Blue Book indicates that traditional archives are "facilities or organizations which preserve records, originally generated by or for a government organization, institution, or corporation, for access by public or private communities." This was often used to designate archives as being distinct from the sorts of archives traditionally maintained by CCSDS Member Agencies, viz. those containing collections of space and earth science data and primarily serving scientists as users.

5.4.4 What Needs to be Defined?

One of the primary contributions of the Reference Model is its terminology, which can potentially allow actors from various distinct streams of digital preservation activity to communicate about and coordinate their work. A major set of decisions in the development of the Reference Model related to what terms should be given formal definitions. A related issue is whether (a) to adopt terms already in use within some particular streams of activity or (b) to instead invent entirely new terms specifically for use in the Reference Model. The Blue Book states, "the approach taken is to use terms that are not already overloaded with meaning so as to reduce conveying unintended meanings," i.e. choosing option (b). While it is true that the Reference Model introduces many new terms, the definitions section of the Blue Book is actually the result of some decisions in favor of option (a) and some decisions in favor of option (b). "Ingest" is a term that was already well-established among space data centers and some other types of data centers, particularly those dealing with telemetry data. Other terms such as "Access," "Administration," "Archive," "Client," "Data," "Data Dictionary," "Data Management," "Edition," "Information," "Long Term," "Management," "Reference Model," and "Version" were already used within numerous streams of activity, i.e. they were "already overloaded," so their use in the Reference Model necessitated clarification over how they should be understood in this context. Some terms appear to have been well-established enough in the vocabulary of participants that they either had a definition that was relatively unquestioned (e.g. "Metadata") or ultimately dropped from the definitions section entirely (e.g. "Format," "Volume"). The term "Digital Object" had been used by the Computer Science Technical Reports (CS-TR) project (Kahn and Wilensky, 1995; Arms, 1995). While the exact nomenclature and definitions were new to the Reference Model, the terms "Content Information," "Context Information," "Fixity Information," "Provenance Information," and "Reference Information," were all adapted from *Preserving Digital Information: Report of the Task Force on Archiving of Digital Information* (1996). Examples of terms or phrases invented specifically for the Reference Model are "Archival Information Package," "Archival Information Collection," "Archival Information Unit," "Designated Community, "Dissemination Information Package," "Independently Understandable," "Open Archival Information System," "Preservation Description Information," "Representation Information," "Representation Network," and "Submission Information Package."

5.4.5 Technical Strategies for Digital Preservation

Another prominent issue in the development of the OAIS is whether and in what ways the Reference Model should address specific technical digital preservation strategies. As discussed in Chapter 1, many of the complexities involved in digital preservation relate primarily to technological dependency. Accessing, understanding and using a digital object requires the coordinated operation of various hardware and software components. Because of innovations in the information and communication technology industries, these components quickly become obsolete and unavailable. Various technical approaches have been proposed for addressing the dependencies involved in long-term preservation of digital information. Two approaches that have often been contrasted with each other are migration and emulation. Broadly speaking, migration-based approaches are based on the transformation of a digital object into a form that can be read directly by current hardware and software (Brodie and Stonebraker, 1995; Dollar, 1999; Wheatley, 2001), whereas emulation-based approaches involve retaining both the original digital object as a bit stream and the original software and then imitating the original computing environment in new computing environments, in order to run the original software (Rothenberg, 1995, 1999a, 1999b, 2000; Rothenberg and Bikson, 1999; Holdsworth and Wheatley, 2001; Lorie, 2001, 2002; Mellor, 2003).

Primarily through interaction with members of the CEDARS and NEDLIB projects, the OAIS development effort received recommendations to ensure that the Reference Model did not preclude the use of emulation as a digital preservation strategy. These recommendations played an important role in the elaboration of the idea of a Representation Network and the further idea that pieces of software can potentially serve as end points of the Representation Network. In the end, the Reference Model takes a middle ground in relation to specific digital preservation strategies. Because it is a reference model, the developers have attempted to avoid implementation-specific language. While not formally excluding emulation, however, some parts of the final Blue Book language do imply a migration-based approach.

There appear to be at least two reasons for the subtle leaning of the OAIS away from emulation. First, although emulation was a very well-established practice in the computer industry, it was still a relatively unexploratory area of digital preservation research. Those actors with experience in maintaining digital objects over time had generally relied on migration-based approaches. Second, the chief actors in the OAIS development and approval process – both as writers and Panel 2 reviewers – had the most direct interest and experience with scientific data sets and users, who may not be as concerned as some other users with dependence on specific software for the rendering, appearance and behavior of digital data. Users often derive value and meaning from scientific data based on sampling, sub-setting and re-aggregating of large data sets (Barkstrom, 1998), which is markedly different from viewing individual documents in their original form. According to one set of authors from the National Snow and Ice Data Center (NSIDC), "The science community is typically more interested in preserving information about how the data were created than in preserving any particular presentation mechanism" (Duerr et al, 2004, p.109).

5.5 Conclusion

The OAIS development began formally within a narrowly defined group (CCSDS voting members) but opened up to include individuals from many organizations and professions. The leaders of this effort decided to promote openness and inclusion in the process, rather than limiting it to those responsible for "terrestrial and space data." Such openness might, at first, not seem surprising. But it is important to remember the mission and procedures of the CCSDS. Any entity that was not a CCSDS member agency had no vote on the approval of the document, so a large number of those attending workshops fell into a broader category of interested "stakeholders" (Moen and McClure, 1994; Moen, 1998) rather than true participants in the SDO decision making process.

By May 1999, the Reference Model had reached the status of Red Book and there was sufficient consensus among the voting members of the standards development bodies (both CCSDS Panel 2 and ISO SC 13) to submit the document for an ISO vote as a Draft International Standard. Based solely on the formal procedures of the CCSDS and ISO, one might have reasonably predicted two possible outcomes at that point: (1) an affirmative vote by ISO national members bodies, which would have allowed the Reference Model to then advance through the ISO process to become an International Standard, or (2) enough negative votes by ISO national member bodies to require revision and resubmission of the document. Instead, the process followed a third path. Even though the Red Book "successfully passed" the balloting process when submitted as a DIS to ISO national member bodies,[45] the leaders of the effort decided to undergo another round of revisions, in order to respond to several comments it had received through channels outside of the official ISO balloting process, especially comments from the NEDLIB project, NLA and Holdsworth from the CEDARS project. In short, rather than progressing Red Book 1 the rest of the way through the ISO process, as they were

[45] Email message from Robert Stephens to François Forestier, Chair of ISO SC 13 (n.d.)

officially endorsed to do, the leaders of the OAIS development effort decided to take a temporary detour in order to accommodate suggestions by actors who officially “did not have a vote” within the CCSDS or ISO. The following chapter provides an account of how and why such a broad set of stakeholders had a hand in the OAIS development effort, while, at the same time, the Reference Model was able to make its way through a formal, bounded standards development process.

CHAPTER 6 – ENROLLMENT AND STABILIZATION IN THE OAIS DEVELOPMENT NETWORK

> *It could so easily have been just a kind of CCSDS model. It could have been a space data systems model. It could have been sort of a 20-page…best practice sort of document. But looking back over the various influences on it, it's quite amazing to think that it has become, or it is, an ISO model...which is supported in so many different disciplines. It could have so easily been otherwise.* (I22)

Chapters 4 and 5 both provide narrative accounts of what happened during the OAIS development process, with the former providing a detailed chronology and the latter presenting a higher level description of trends and patterns. Those two chapters are based primarily on analysis of documentary sources, though interview data provide some of the basis for the account. Chapter 6 looks at how and why the process played out the way it did. The findings in this chapter are based primarily on analysis of interview data, though it also presents some findings based on synthesis of more specific products of my document analysis. The OAIS development process was characterized by two broad sets of forces: active enrollment of resources from the environment, while also stabilizing elements of the Reference Model's content in a way that made it decreasingly likely to be altered by inputs from the environment.

6.1 Enrollment of Resources from the Environment

> ***Finding 1: The OAIS development process enrolled resources from the environment.***

Networks of actors and artifacts can gain prominence and influence by "enrolling" resources from the environment (Latour, 1987). These resources then effectively become part of the network. The actors and artifacts initially associated with the OAIS development effort become more visible, prominent and effective through a process of continuously drawing in new and varied resources from the environment.

> The reference model represented common ground upon which to consolidate understanding of the needs and requirements of digital preservation: an opportunity to gather the strands of isolated digital preservation activities, merging them into a shared (albeit highly conceptual) characterization of the problem's boundaries. (Lavoie, 2004, p.2)

6.1.1 Types of Resources Enrolled from the Environment

In this study, I have borrowed the concept of enrollment from actor-network theory (ANT), which treats all enrolled resources (human or non-human) into a broad category called "actors." While such an approach has the value of highlighting the deep connections between the social and artifactual elements of technology and technical evolution, it also has the risk of obscuring the unique role of human agency. In order to examine the development of the OAIS, it is very useful to distinguish between several different types of resources enrolled by the actors (individuals and organizational entities) involved in the process.

> ***Finding 1.1: The resources enrolled in the OAIS development process took several different forms.***

6.1.1.1 Skills and Expertise

The actors involved in the OAIS development effort brought a varied set of skills and expertise. Many had experience with modeling and other formal design techniques, and many could also draw from their experience in managing and preserving digital information in their own organizational contexts. Several interview participants also commented that they were able to bring to the process an understanding of the needs associated with the users they served. While some emphasized their ability to master the numerous technical details, others commented on their ability to read the Reference Model as an uninformed reader might and offer suggestions for how explanations could be simplified in order to make sense to such audiences. Several participants, who had daily responsibility for the management of digital information, indicated that they were able to provide periodic "reality checks" by indicating whether or not aspects of the Reference Model were consistent with their own experience. For those individuals who consistently participated throughout the OAIS development process – which took several years, involving many meetings and many document drafts – two factors that should not be overlooked are patience and persistence. According to one participant, "I wasn't afraid of the amount of work or time involved in doing standards work. I knew it was a long, tedious process, and sort of a frustrating process." (I1)

6.1.1.2 Social Ties

The development for the OAIS drew on many pre-existing social ties between actors as well as social ties that emerged during the time the OAIS was developed. Several core participants in the OAIS development process also had close working relationships and had been involved in many projects together in the past. For example, Sawyer and Reich have worked with each other for 20 years and tended to talk with each other on a daily basis. At a slightly higher level of aggregation, an important existing social network involved actors who regularly participated in CCSDS meetings. On the trips associated with the CCSDS meetings, the participants would often bring their spouses with them and interact socially outside of the meetings, and this gave them a "more cohesive bond" (I1) than might be implied simply based on their co-membership in a standards development organization (SDO). An even broader social network involved those generally involved in the management of space science data. "Most of the players know each other, just because they keep running into each other, because they have interfaces to each other, or they stumbled across each other at a meeting or something like that." (I14) Given the international nature of many space initiatives, the social networks among space science data actors already included many international connections (I10).

Another important social network was composed of actors involved in work on mass storage systems and technologies (MSST). The main formal events associated with MSST were two series of annual conferences held by the IEEE and GSFC (held jointly starting in 1998). A number of actors who participated in ISO Archiving Workshops also took part in one or more MSST conferences. As explained in 6.1.2.3, the MSST events served as forums for both the dissemination of information about the development of the Reference Model and recruitment of actors into the process.

Many social connections also emerged during the development of the Reference Model, and those connections could then be enrolled in support of the Reference Model development effort. For example, those involved in initiatives that attempted to apply and test the Reference Model – CEDARS, NEDLIB, British Library and PANDORA – engaged in conversations related to their work that took place outside the context of ISO Archiving Workshops. Those involved with archives certification work that built off of the Reference Model also established and reinforced social connections that also allowed them to share ideas that contributed to the formal and informal comments that they provided to the CCSDS and the Reference Model editorial team.

6.1.1.3 Documentary Artifacts

Development of the Reference Model drew from many documentary artifacts from the environment. These included concepts, terminology, models, strings of text and images, coming from guidelines, reports, and standards. In some cases – such as the "Z39.50 Profile for Access to Digital Collections" (PDC), *Preserving Digital Information*, *Planetary Data System Data Preparation Workbook,* IEEE Portable Operating System Interface Open Systems Environment (POSIX OSE) Reference Model – it is possible to identify specific terms or concepts that were incorporated into the Reference Model. Other artifacts were discussed during Workshops and provided varying degrees of conceptual background for the work on the Reference Model, e.g. IEEE Mass Storage Reference Model, *Preserving Data on Our Physical Universe*, documents that Claude Huc submitted early in the process, and several CCSDS standards related to data representation, formatting and description. There are also several documentary artifacts from the environment that have a "family resemblance" (Wittgenstein, 1958) to parts of the Blue Book, suggesting a shared conceptual lineage rather than reuse through direct copying. For example, the Layered Information Model has some similarity to the PDS model, composed of four layers – Structure, Stream, Object and Label – about which J. Steven Hughes of the JPL submitted a paper at DADs. Several of the entities in the model presented in Version 1 are notably similar to those in the archive model laid out by NASA in the 1960s (see Figure 1), and several key terms in the OAIS had been used in NASA's "Comprehensive Cost Model for NASA Data Archiving" (Green et al, 1990). The Object Modeling Technique (OMT) and then Unified Modeling Language (UML) were enrolled in order to give clarity and precision to the representation of the functional model and information model.

Another vital documentary artifact that was enrolled in the OAIS development effort was the World Wide Web, which had only been invented a few years earlier, in 1991. Garrett developed and maintained an extensive collection of Workshop and other related documents on the Web. In 1995, the use of the Web for documenting SDO activities was very unusual (though the IETF and W3C were two consortia that had done so). According to one participant, dissemination of documents through the Web was an essential facto in the success of the OAIS development effort. "Holding two [Open] Workshops was one thing, but our web pages were purely open." (I3) This online presence played a pivotal role in the coordination of work on the Reference Model and enrollment of actors from the environment. Actors could obtain versions of the Reference Model and associated documentation without having to ask members of the CCSDS for copies, which meant that they could also make use of the Reference Model without the OAIS team being aware that they were doing so (I4). Members of the NEDLIB project, for example, first learned about the Reference Model through the Web and began using it for their own work. It would then be another two years before Titia van der Werf reported on the NEDLIB work to the OAIS development team.

6.1.1.4 Structures and Routines

Routines can be valuable resources for an organization or other social group (Nelson and Winter, 1982). Established patterns of activity and the social structures that support them can serve as units of organizational memory, which can be transferred to next organizational contexts (Argote, 1999; Argote et al, 2000). The OAIS development effort benefited considerably from the enrollment of structures and routines that were already in place when the ISO Archiving work package was initiated. Because the development of the Reference Model took place within the CCSDS, the International Workshop could be organized as simply another set of agenda items on the program of the semi-annual CCSDS meetings that had been in place for years. The CCSDS also provided a set of established practices and conventions for the shepherding of standards through various levels of internal adoption. With its formal liaison relationship to the ISO, it was also relatively straightforward (though as several interview participants commented, still slow and tedious) to pass the final Blue Book through the ISO for balloting and then publication as an International Standard. In addition to being the leader of the OAIS effort, Sawyer was also head of NASA's Office of Standards and Technologies (NOST). Sawyer, several members of his staff and contractors with whom he worked were accustomed to standards development activities and were able to enact routines related to the group facilitation, consensus building, decision documentation and project management required to successful develop a standard.

The embedding of the OAIS development effort within existing CCSDS structures and processes had two important effects on participation. First, it drew in many actors who might not have otherwise participated in OAIS discussions. Attending the semi-annual CCSDS meetings generally involved also taking part in the ISO Archiving International Workshops, so the International Workshops included representatives of Member Agencies who took part in the CCSDS for a variety of reasons other than digital archiving. One such individual stated, "I was there, a little bit by chance, because I was working on related topics" and did not have "a very big background" in archives. (I8) Another commented, "I was involved in this [CCSDS] Panel [2] work already. Naturally, I worked in this new study, because that was part of the Panel work" (I12). Second, the need to discuss CCSDS issues relatively unrelated to digital archiving (e.g. telemetry standards) created a disincentive for non-Member-Agency actors to take part in International Workshops and related phone and email conversations. During teleconferences of core team members, "there'd be 5 or 6 topics and the OAIS would be one of them," so taking part in the part of the conversation devoted to the OAIS could require sitting through hours of discussions related to other CCSDS activities (I1). An individual who participated in two early US Workshops,

> actually started talking to these folks, getting on various mailing lists, where I was expected to review [CCSDS] standards. And that was always entertaining, seeing the standard come by on what the telemetry bit pattern was for such and such communication path to the ground. Like do I care? I don't particularly care. (I14)

In addition to resources of NASA and the CCSDS, Ambacher and NARA were also able to enact structures and routines related to hosting meetings. This allowed them to offer Archives II as the location of many ISO Archiving Workshops.

6.1.1.5 Physical Facilities and Proximity

Although teleconferencing, email and the Web greatly facilitated work on the OAIS among actors who were often not physically co-located, geographic location still played an important role in the OAIS development process. This is consistent with previous research, which has demonstrated that, despite the availability of information and communication technologies that support remote interactions, spatial proximity can still often serve as an essential factor in the likelihood of actors to collaborate (Allen, 1977; Kraut et al, 1990), their success in collaborative work (Olson and Olson, 2000), and development of technological innovations (Castells, 1996; p.53-58, 388-392; Ratti, Bramanti and Gordon, 1997; Saxenian, 1994).

The GSFC is located in Greenbelt, Maryland. Within a radius of just a few miles of the GSFC are also located numerous government facilities, government contractors and research centers responsible for large data sets and collections. The area is also home to many actors involved in the mass storage systems community.[46] The geographic area immediately surrounding the GSFC, therefore, provided a rich set of human and institutional resources with a potential interest in digital archiving standards. Almost two-thirds of the ISO Archiving Workshops that took place within the scope of my study (22 out of 36), both of the Open Workshops that were held in the US, and all of the US Workshops, took place in Maryland within 25 miles of the GSFC (18 in College Park and one each in Annapolis, Greenbelt, Silver Spring, and Laurel).

By far the most frequent venue for ISO Archiving Workshops (DADs, AWIICS and 15 of the 18 regular US Workshops) was the Archives II facility of NARA, located in College Park, which is about an eight-mile drive west of the GSFC. Hosting workshops at Archives II allowed NARA to contribute a value service to the OAIS development

[46] There are also several major mass storage system actors on the West Coast, particularly California. Those West-Coast actors, however, are generally more likely to be concerned with reliability and performance than the East-Coast mass storage actors, who often have more responsibility for long-term custody and dissemination of digital information (I6).

effort while also showing its new (opened in January 1994) facility and operations to participants. One participant whom I interviewed indicated that a significant motivation for his[47] participation in US Workshops was to take part in the tour of Archives II and gather information about how NARA managed its materials and environmental controls (I18). While it was extremely convenient to hold Workshops in a location so close to the home offices of several core team members, it was also useful to meet in a place outside the grounds of the GSFC. Being a few miles away from the GSFC made Archives II a "kind of neutral territory" (I4) in two important ways. First, it helped to counteract the impression that the OAIS development effort was simply a NASA project. Second, the participants from GSFC could take part in focused periods of work on the Reference Model with much less interruption than they would encounter if they attempted to conduct the meetings in their own facilities. In fact, those with writing and editorial responsibilities, particularly Sawyer and Reich, would often spend an additional day or two working at Archives II after the formal US Workshops had adjourned.

Although Archives II was conveniently located for several actors with a strong interest in the Reference Model, there were also several important actors who had to commit significant amounts of money and time in order to participate. According to one core team member, the actors from the West Coast who had an interest in participating had indicated that they had more ability to travel than those on the East Coast, which was one factor in the decision to hold the US Workshops in the DC area (I4). However, many

[47] In order to ensure their anonymity, when using pronouns to identify interview participants, I have selected the gender of the pronouns randomly. One should not assume from the use of a masculine pronoun that a given participant is male or from the use of a feminine pronoun that the participant is female.

interview participants did mention travel as either a challenge of participating or a contributing factor in their decision to stop taking part in the OAIS development effort.

The International Workshops took place within the context of CCSDS semi-annual meetings, which take place somewhere in Europe each spring and somewhere in the US each fall. This arrangement likely resulted in a much more geographically diverse set of participants than there would have been if development of the Reference Model had taken place within an SDO based directly in the US, such as NISO; but it did also create a barrier for members of the US core team to participate in the CCSDS Panel 2 discussions that took place at the International Workshops outside the US. Several very active participants and contributors at the US Workshops – Ambacher,[48] Martin, Stephens and Grunberger – did not travel to the International Workshops held in Europe in order to take part in the OAIS discussions.

When they occurred in the US (as part of fall CCSDS meetings), the International Workshops often took place outside of Maryland; of the six Workshops, two were held in Maryland, three in California and one in Texas. In comparison with the US and Open Workshops, the International Workshops were more closed forums, primarily concerned with formal evaluation and review by the CCSDS Member Agencies, so they were not ideal avenues for peripheral or new participants. During interviews, however, two individuals who were important to the OAIS development process but did not attend a large number of meetings, both mentioned that they participated in an International

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[48] Ambacher did travel to the Eleventh and Thirteenth International Workshops, but this stemmed from his contribution to the follow-on certification effort, rather than the development of the OAIS Reference Model itself.

Workshop, in part, because the Workshop was held in California, where they lived (I17, I19).

6.1.1.6 Funding Streams

One of the essential resources upon which actors drew in the development of the OAIS was pre-existing and emerging funding streams. As mentioned by several of the individuals I interviewed, development of CCSDS standards is a volunteer activity, in the sense that the CCSDS does not directly pay actors to contribute to the process. Because reference models are very high-level and largely anticipatory standards, the final product of a reference model development process is also not likely to yield short-term financial benefits to those involved. Spring and Weiss (1994), therefore, predict that private sector actors will tend not to invest heavily in the development of reference models. Their prediction holds true in the case of the OAIS development effort, which was largely dominated by actors from government agencies, contractors paid by government agencies, universities and nonprofit professional associations.

Funding for participation generally fell into one of three categories. The first category is provisions within the budgets of CCSDS Member Agencies (space agencies) and their contractors specifically for taking part in standards development activities, usually even more specifically for taking part in CCSDS activities. Based on their institutional commitment to the CCSDS, many Member Agencies had incorporated the human resources and travel expenses associated with CCSDS activities as part of their cost of doing business. The second category of funding was "slack" resources of organizations which participants or their supervisors had discretion to spend. Because it was not part of their regular operating costs, one would expect organizational actors that were not CCSDS Member Agencies to take part in the OAIS develop effort – which was novel, risky and with potentially little or no direct short-term payoff – only if they had slack resources within their organization that could be enrolled to fund their participation (Cyert and March, 1992; Damanpour, 1991; Rosner, 1968). The final category of funding was grant money provided to research projects that involved some elements of testing or applying the Reference Model. One striking aspect of these three categories of funding for participation is that none of them had been directly earmarked for the OAIS effort itself. Enrollment of these resources was by no means assured from the start, and it was one of the chief accomplishments of the effort.

In addition to funding the actors' participation, the OAIS development effort also required funding for the workshops. For the International Workshops, the OAIS effort was able to draw on the existing stream of resources coming from the CCSDS, which had been holding semi-annual meetings for many years, and the organizations that offered to host each workshop. The Open Workshops and US Workshops were the events that made the OAIS development effort so different from other CCSDS standards efforts, and they could not have happened without the enrollment of available financial resources. The Open Workshops drew from a variety of funding sources. NASA, NARA and the ISO/CCSDS were major organizers for the Open Workshops that took place in the US (DADs and AWIICS), though several other organizational actors also sponsored DADs: Committee on Earth Observation Satellites (CEOS), Johns Hopkins University - Applied Physics Laboratory (APL), and Research Libraries Group (RLG). The CNES was responsible for the French Workshop; BNSC hosted the UK Workshop in cooperation with the CCSDS and ISO; and Digital Curation was sponsored by BNSC and the Digital Preservation Coalition.

As described in Chapters 4 and 5, the Open Workshops played an essential role in the OAIS development process, in terms of diverse input and visibility. The arenas for the bulk of the detailed writing and editorial work, however, was the consistent series of US Workshops, which were made possible by NASA and NARA. One interview participant emphasized the importance of having funding for the US Workshops. She indicated that CCSDS Member Agencies, such as BNSC, CNES, DLR, and the ESA generally

> didn't have specific funds to bring people together [for ongoing series of workshops]. Whereas NASA, I'm pleased to say, did. And that was a really critical component of the work, because if there had not been funding...from NASA for a lot of workshops, bringing together people from many different disciplines from the sciences and from the sort of more document tradition, then OAIS would not have been as widely accepted. (I22)

6.1.2 Enrollment Efforts of Actors Involved in the OAIS Development Process

The OAIS development effort involved a diverse network of actors and resources, which underwent changes throughout the seven-year process. One should not infer from the wording of Finding 1, however, that the development of the OAIS was simply a result of systemic or institutional forces outside the control of any particular actors.

> ***Finding 1.2: Enrollment from the environment was based on a concerted effort by actors involved in the OAIS development process.***

The leaders of the effort carried out numerous intentional acts to enroll resources from the environment. Most of the individuals whom I interviewed praised Sawyer for framing and orchestrating the OAIS development process in a way that was inclusive of a broad set of interests outside the traditional set of CCSDS Member Agency actors. Many interview participants also commented on Reich's role in successfully opening up the process. One individual stated that Sawyer and Reich were "very far-sighted to see really how we could attack this" so broadly (I22), rather than simply pursuing the Reference Model as a space data standard. This could not only serve the interests of actors in the environment but also benefit the advancement of standards within the space science data arena. A standard that had the buy-in of a large and diverse "technological community" (Von Burg, 2001) that included non-space-agency players was more likely to gain the attention of vendors and could also seem more legitimate to space agency staff. However, not all members of CCSDS Panel 2 shared the view that opening up the process was a good idea. Enrollment of actors and other resources from the environment was not free. It cost time and money. There were some within the CCSDS who said, "If anyone else likes this, why aren't they paying for it, instead of us?" (I2) Part of the work of enrollment was to continuously make the case for openness, in response to such objections.

Sawyer, Reich and several other core team members were instrumental in setting and perpetuating a trend toward enrollment of resources from the environment, but they did not act alone. The structuration of the Reference Model's meaning, importance and prominence involved numerous interactions among a wide array of actors (Giddens, 1984). The enrollment of resources from the environment involved many acts and events that might seem peripheral or even irrelevant if one were to look exclusively at the actors and decisions that took place within the formal CCSDS structure.

6.1.2.1 Search for Literature

The leaders of the OAIS development effort actively searched for existing literature or standards that might be relevant to digital archiving. One participant explained that he was convinced at the First US Workshop that development of the Reference Model was an important and legitimate standards effort. One of the main reasons for his positive assessment was that Sawyer and Reich had obviously conducted a "very conscious, global literature search." (I1).

As explained in chapter 4, Squibb's initial proposal in April 1994 to SC 13 was to "define the formats for archiving data from space missions." Based on an initial search of existing guidance documents and their own experience with space data, Sawyer and Reich came to recognize three things. First, space data centers were already committed to a diverse set of data formats, making it unlikely that a standardization effort could be successful if it attempted to start at such a low level of abstraction. Second, no other professional community appeared to have developed a single, coherent set of standards for the archiving of their data. Third, those guidance documents that were available used terminology in very inconsistent ways. So Sawyer made a pitch to NASA management for much more high-level standardization effort, beginning with the development of a reference model. Reich and Sawyer's Version 1 of the Reference Model did not explicitly cite any outside literature, but later versions did include several such references.

Reich and Sawyer continued to seek out relevant materials throughout the OAIS development process. The Open Workshops also contributed substantially to the literature review effort, because the OAIS team was able to read and review the proposals and papers that were submitted for the workshops. Many of the projects and activities in the environment related to digital archives also put documents on the Web, which helped the OAIS development participants to identify and obtain copies of relevant literature.

6.1.2.2 Framing of the OAIS Development Effort as Open and Inclusive

An important factor in the enrollment of actors and other resources from the environment was the leaders' framing of the process as open and potentially relevant to anyone interested in digital archiving, not just space data centers. "From the first meeting, they knew that…they wanted this to be more than just a space community effort, for contribution to more than just the space community. That was very clear from the very beginning." (I1) Sawyer "was able to say, 'We are going to bring in the expertise from outside, and not try to do this on our own.'" (I2)

6.1.2.3 Promotion and Recruitment at Professional Events

Core members of the OAIS development effort gave dozens of presentations related to the Reference Model at conferences and other professional events (see Appendix 2). This not only pushed information out to external actors but also drew attention and resources into the OAIS development effort. Perhaps even more important than the official presentations were less formal conversations that took place at the professional events. Long before the Reference Model had reached Red Book status (and was thus officially subject to public review), Sawyer was telling many individuals at conferences about the Reference Model and attempting to recruit them into the development and review effort. Several interview participants reported that this is how they first heard about the Reference Model. One particularly fruitful venue for social networking was the annual IEEE/Goddard Mass Storage Systems conference.

6.1.2.4 Enrollment through Participation

> *[My supervisor] wanted to make sure that we sent somebody that was manager level, you know, at that point, so people would understand how important it was to us…* (I19)

In addition to their many valuable substantive contributions to the content of the Reference Model, core team members also played an important role in the broader processes of structuration surrounding the standard. Actors often served (either explicitly or implicitly) as representatives of particular communities. The significant commitment of core team members to the OAIS development effort signified and legitimated the Reference Model as something of relevance to their respective communities. One very important example is Bruce Ambacher, whose active participation throughout the entire process, as well as his orchestration of NARA hosting numerous workshops at Archives II and discussion of the OAIS work with his professional colleagues, sent a strong message that the Reference Model was potentially relevant to institutional archivists and manuscript curators. In turn, Ambacher's involvement signified and legitimized both NARA, and the archival profession more broadly, as the sort of actors that had important things to say about a reference model for archival information systems.

Several other core team members played a similar role, by representing subsets of the larger set of actors traditionally associated with the CCSDS. The participation of Mike Martin signaled a connection of the Reference Model to the JPL and the set of actors surrounding the Planetary Data System (PDS). Alan Wood's involvement tied the OAIS effort to NASA's Human Space Flight and Life Sciences interests. The active involvement in International Workshops and promotion of the OAIS by David Giaretta contributed to an association of the Reference Model to the BNSC and other UK actors, while Claude Huc and Patrick Mazal played a similar role in relation to CNES and other actors in France.

Several more peripheral participants also played important roles in the processes of structuration surrounding the Reference Model. For example, a cluster of several concepts was drawn in from work by the Report of the Task Force on Archiving of Digital Information. A series of interactions contributed to the mutual definition and framing of the two efforts in relation to one another. The signification and legitimation of both efforts involved reference to *Preserving Digital Information* as related reading for workshops, citation to *Preserving Digital Information* in drafts of the Reference Model, and incorporation of its concepts into the Reference Model's information model. However, the structuration also involved more purely social acts: Don Sawyer and later CCSDS Panel 2 discussed the work of the Task Force as being important; Sawyer discussed the effort with Don Waters (co-chair of the Task Force); the US team sent a formal letter to RLG, signifying a formal connection between the two efforts; the US team sent a message directly to RLG, asking them to take part in the DADs Workshop; Waters and a representative from RLG, Anne Van Camp, later attended the DADs workshop, further signaling to many actors in the environment that the borrowing of the concepts was associated with at least some reciprocal indication of support for the OAIS work; and Robin Dale of RLG then took part in several subsequent meetings. These activities involved the mutual exchange of useful information, but just as importantly, they served as signals about what the OAIS meant and how it should be perceived. The

OAIS was a standard that "cultural heritage" (I19) professionals (i.e. librarians, archivists and museum curators) should care about, and, in turn, those responsible for the development of the OAIS cared about the concerns of cultural heritage professionals.

Several individuals from the UK, who were only peripherally involved in ISO Archiving Workshops, also played an important part in the enrollment of resources for the OAIS effort. David Holdsworth of Leeds University, for example, participated in only one ISO Archiving Workshop, but he took on a valuable bridging role by bringing the OAIS development effort to the attention of several actors, who were outside of the space science data arena and who then provided input to the OAIS development process. Neil Beagrie and Daniel Greenstein of the AHDS wrote about the Reference Model very early in the development process in their "Guidelines for Digital Preservation" and then shared a paper at the DADs Workshop about their AHDS document. Greenstein took part in one ISO Archiving Workshop and Beagrie participated in five, but participation figures alone fail to fully capture the role that they played in the OAIS development process. Both men were key actors in the development of a digital preservation community in the UK, a process that was occurring at the same time that the Reference Model was being developed and approved. Their early and ongoing attention to the Reference Model was instrumental in signaling its importance in the UK and elsewhere.

6.1.3 Benefits and Costs of Active Enrollment Efforts

> ***Finding 1.3: Efforts to enroll a very broad set of resources yielded both significant benefits and costs.***

The above discussion has touched on many of the benefits associated with the enrollment of a broad set of resources. The most obvious benefit is that the effort had a more diverse set of resources from which to draw. Actors from a wide array of institutional and professional contexts could offer examples, cite standards, and draw on expertise and abstractions that would not have been available if the OAIS development process has involved only CCSDS Member Agencies and their contractors. Broad and inclusive enrollment – and the perception of broad and inclusive enrollment – were also extremely influential in the structuration processes surrounding the Reference Model. The meaning and importance of the Reference Model were not tied exclusively to NASA or even exclusively to space agencies. There were institutional archives, libraries, and data centers outside of the space domain that had a stake in the outcome of the OAIS development effort and associated it, at least to some degree, with their own roles in the arena of digital preservation.

The costs of broad enrollment of resources, however, were certainly not negligible. One major challenge associated with such a broadly conceived effort was the ambiguity and negotiation over scope, objectives, expectations, and terminology. The stabilization of meaning around parts of the Reference Model that emerged over time (see Finding 3) was the result of active discussion and hashing out of ideas. It was not something that could be taken for granted from the start of the process. Another consequence of the opening up of the Reference Model development effort was delay in the completion of the standard. The projected Blue Book completion date was moved from spring 1997 to May 1998 to December 1998 to May 1999 to January 2002.[49]

[49] In fact, ISO's initial expected completion date of a Committee Draft (a White Book within the CCSDS) was even earlier: November 1995. However, moving the work to SC 13, with a different associated New Work Item proposal, "reset the ISO clock on development of this work" (Sawyer, 1995a).

6.1.4 Selective Enrollment of Resources

It is possible to identify any number of resources from the environment that could have potentially been relevant to the development of the OAIS. In fact, only a small portion of those potential resources played a part in the story I tell in this study. Notably absent from ISO Archiving Workshops were potential stakeholders such as content producers, records managers, auditors, museum curators, attorneys, data end users, and members of data-intensive industries such as pharmaceuticals, petroleum, health care and insurance. Until AWIICS (four years after the first Workshop), Ambacher from NARA was the only institutional records archivist to participate in workshops, and he was the only individual from NARA to attend more than one workshop. Participation of individuals associated with libraries in US and International Workshops was very limited. The Library of Congress (LC) sent only one individual to one Workshop, even though LC has a large stake in digital preservation activities and is geographically proximate to both GSFC and Archives II. As discussed in Chapter 2, there were also numerous documentary artifacts in the environment that had been generated from the streams of activity related to digital preservation. Only a small subset of those documentary artifacts were enrolled in the development of the OAIS.

> ***Finding 1.4: The resources drawn from the environment were only a small subset of all potentially relevant resources in the environment.***

When attempting to find solutions to novel problems in the environment, social systems do not scan the entire environment. Instead they engage in patterns of limited search that reflect their own internal structure (Cyert and March, 1992; March and Simon, 1958) and large social networks in which they are embedded (Granovetter, 1985). William Moen argues that during different stages of the evolution of a standard, different aspects of the environment may be relevant. Moen posits that only a subset of the larger environment needs specification, and this subset constitutes the relevant environment for the standards work.

> The relevant environment consists only of those entities and forces (e.g., people, organizations, installed technology) from the broader socio-technical environment that at any given time influenced, affected, shaped, or otherwise conditioned the opportunities and limitations of the system (Moen, 1999, p.5-5).

Both the relevant environment and "relevant social group" (Pinch and Bijker, 1984) change over time.

In order to play a contributing role in the OAIS development process, resources also needed to be "enrollable." The enrollment of actors involves agency not only on the part of those doing the enrolling but also those being enrolled. Actors in the environment had to become aware of the OAIS development effort, but they also needed the appropriate combination of incentives, expertise, and institutional support to contribute to the Reference Model's development. As discussed in Section 5.4 below, it was also important for interested actors to see contribution to the OAIS effort as more desirable than the other available alternatives. If an alternative reference model had already been in place, for example, many of the actors with relevant expertise might have simply applied their knowledge elsewhere. The enrollment activities of the actors in the social network surrounding the OAIS were not simply unidirectional actions but were instead a series of "double interacts" between the actors involved (Weick, 1979, 1995). Actors in the environment responded to the messages they received from within the OAIS network, and the responses from actors in the environment, in turn, shaped the messages being generated by those within the OAIS network.

As with actors, not all potentially relevant documentary artifacts from the environment were enrollable for the OAIS development effort. First, artifacts had to fit within the existing notion of the Reference Model's scope. As explained in Section 5.3, the notion of what might be relevant to the Reference Model changed over time, but it became increasingly stable over time. Second, even if they were perceived as falling within the scope of the Reference Model, and thus relevant to the development effort, the characteristics of some documentary artifacts made them more amenable to enrollment than others. Those characteristics are the topic of Finding 2.

6.2 Role of Modularity and Abstraction in Reference Model Contributions

> ***Finding 2: Documentary artifacts were most successfully incorporated into the Reference Model when those artifacts from the environment were perceived (a) to support the modularity of the Reference Model and (b) to be at the appropriate level of abstraction.***

The above finding holds for artifacts enrolled from the environment, but it also applies to artifacts invented specifically for the Reference Model.

6.2.1 Modularity

When engaging in design and modeling efforts that relate to large, complex systems, modularity can be extremely valuable (Gauthier and Pont, 1970). In a modular design, there are relatively distinct elements (modules), which are tightly coupled internally but only loosely coupled externally. An essential condition for modularity is that the interfaces between modules must be explicit, clear, and relatively simple. Modularity is a matter of degree (Schilling, 2000) and is thus most easily applied in relative terms (Ulrich, 1994, p.220), i.e. one system or system design approach can been said to be more modular than another. The concept of “module” is very similar to that of “black box” used in cybernetic and then later by actor-network theorists. A black box is “a piece of machinery or a set of commands,” which is placed conceptually within a box about which one needs “to know nothing but its input and output” (Latour, 1987, p.2-3). During periods of transformation, the characteristics and boundaries of technological components are still open to various interpretations. It is only after active discussion, negotiation and formal codification that a module or black box can be treated as such.

Limiting the interdependencies between subsystems can also make a design more robust against disruptions from the environment (Simon, 1962). Modularity can reduce the switching costs associated with adopting standards (Wegberg, 2001) and potentially allow a relatively simple standard to meet the needs of a diverse set of requirements without having to delineate all of those requirements in advance (Lagoze, 2001). Modularity can allow both suppliers and consumers to “mix and match” components to meet their particular needs or perceived needs (Langlois and Robertson, 1992).

With a modular design, actors can engage in innovation and implementation related to the internal design of separate modules without disrupting the overall interoperability of the system. The internal details of modules are “hidden information” to those looking at the module from the outside. Actors who want to adopt, incorporate or interact with a module need only to understand the “design rules” that define its interfaces (Baldwin and Clark, 2000). This can be particularly valuable in a complex and dynamic problem space, because the interactions between modules can remain predictable, while internal changes to modules can occur at varying rates (Baldwin and Clark, 1997). When the modules are part of a system based on open standards, “autonomous innovation can occur not only in one module, but also across several modules” (von Burg, 2001, p.42).

The Reference Model has an “organization, in which the problem [of digital archiving] is split in[to] several smaller problems.” (I10) Both the functional model and information model are based on a small set of high-level elements that one can then examine in more detail at lower levels of abstraction. At any given level of abstraction, there are an explicit set of interfaces between the modules. One interview participant commented that the clear definition of functions and their interfaces in the functional model early on greatly facilitated a common understanding among the OAIS development participants about where particular activities within an archival information system should be placed within the model (I12).

The incorporation of elements from the environment into the Reference Model was strongly influenced by issues of modularity. In explaining why parts of *Preserving Digital Information* might have been so easily incorporated into the Reference Model, one individual remarked that “frameworks are hierarchical, and part of the problem of taking a framework is that you have to make assumptions about what surrounds it.” *Preserving Digital Information* “provided some of that larger framework.” The developers of the Reference Model “could say, ‘Okay, well, there are these other issues that the framework is going to fit within.’” This meant that the Reference Model “didn’t have to keep pushing out to these other issues,” such as organizational, legal and economic considerations. “But assuming those, here are the technical questions that we’ve got to address. And so they could burrow down to the next layer of real technical work, making some assumptions about how that framework fit into the larger picture." (I15)

One fundamental reason that the Preservation Planning entity could be added so late in the process, after the functional model had been strongly stabilized (see Finding 3), was that it is relatively self-contained and did not introduce a large number of complex interactions with or between existing entities. Given that it was a relatively self-contained module, it was possible to "plop in" Preservation Planning with minimal disruption to the rest of the Reference Model (I19). Not all of the core participants were initially convinced that the new entity added much conceptually to the functions of the Reference Model, but it became clear that there was considerable rhetorical force associated with the addition of the word "preservation," and the addition was likely to yield "greater acceptability" (I1) among institutional archivists and librarians. Because the Reference Model "is only concepts, it is very dependent on public buy-in. And that, I think, was a big point, because no longer, did they feel that they were on the outside, they were on the inside." (I3) Given that "it doesn't hurt anything to add it," (I1) the choice made sense.

Other proposed changes would have implied substantial reconceptualizing and rewriting of content throughout the Reference Model, and thus was met with more resistance. For example, when some actors raised concerns about how the Reference Model addressed "the designated community, which permeates throughout the document, and has vast implications on all the other processes within the functional model, there was less movement on that." (I19) The Seventh International Workshop on October 25-30, 1998, participants rejected suggestions to replace with the word "Ingest" with

“Acquisition.” At that Workshop, participants also decided not to incorporate suggestions to more thoroughly incorporate the concept of “record” as that term was used in the archival profession. Instead, they added a paragraph (in White Book 5) to the terminology section, acknowledging that many disciplines – including “archival science [which] focuses on preservation of the 'record’” – will “need to map some of their more familiar terms to those of the OAIS Reference Model.” At the Ninth International Workshop in November 1999, Panel 2 rejected a change that NARA had proposed a month earlier in a RID. NARA had suggested adding text to the definition of “Archives” that would make it consistent “with other archival Standard definitions with the International Council on Archives (ICA) Glossary.” Panel 2 decided to reject this “overloaded definition,” which would have had significant implications for many parts of the existing document. Instead, Red Book 1.1 includes a brief addition to one of the appendices, which suggests “approximate mappings” between terms from the Reference Model and those used in “traditional archives” (Archives, Accession, and Record – mapped to OAIS, Ingest and Content Information, respectively) and a term traditionally used for journals (Primary Audience – mapped to Designated Community). As with the earlier change to the terminology section, the new text in Red Book 1.1 was a modular response; it explicitly acknowledged the concepts from “traditional archives” and libraries without having to either discuss the internal complexity of those concepts or alter the rest of the document to directly accommodate them.

Parts of the Reference Model that were created specifically for the document (rather than borrowed from elsewhere) were also subject to modularity considerations. In White Book 3, two entities that had been in the functional model since Version 1 of the

Reference Model, Access and Dissemination, were combined. In an email message that he sent (April 7, 1998) on behalf of several members of the core team, Sawyer explains that they had spent considerable effort "attempting to partition the functionality among Access, Dissemination, and Data management. We have come to the conclusion that there are too many optional ways to do this, and picking one results in the flavor of an implementation, not a refernece [sic] model." According to one participant, "the interactions seem to be too complicated" with separate entities for Access and Dissemination (I4). The eventual response was to create a more inclusive entity, so that many of the complicated interactions were "hidden" from view in the functional model. This was not a denial of the need to address the interactions, but it was instead a decision to leave those details out of the Reference Model, to be addressed later by implementers and possibly more specific derivative standards. The elimination of a Dissemination entity, as distinct from Access, also allowed the Reference Model to be more applicable to "dark archives," which do not distribute data to the external users. In this way, the functional model is more agnostic toward the access and use policies of archives.

6.2.2 Level of Abstraction

Abstractions are good at hiding complexity while still recognizing its existence. When determining what to include in the Reference Model, both aspects of abstraction were important. While precise language, formal modeling (e.g. use of UML), and elaboration of small details related to the boundaries of entities were all important, an essential factor was also the ability to "distill out the abstract form of the concepts." (I7)

In relation to the decision to abandon an effort to include a taxonomy of archives within the Reference Model, for example, one of the core team members remarked that there were too many “dimensions.” In order to include a discussion of classifying archives within the Reference Model, “you either had to deal with them in excruciating detail or excruciating fuzziness.” (I3) Members of the OAIS development team found *Preserving Digital Information* to be a very useful source, because they could easily map some of its elements directly into what would become *Preservation Description Information*. This mapping was possible because the elements of *Preserving Digital Information* were both formally specified and, for the purposes of the Reference Model, they hid an appropriate amount of complexity.

Within a standards development organization, mutual determination of the appropriate degree of abstraction is not only a technical but also a political process. In order to settle on the level of specificity associated with a component or concept, actors consider not only what would be most appropriate for driving future design but also what would be most consistent with their own existing (or planned) understanding and practices of the problem space addressed by the standard.

> In standards meetings, many hours will be spent choosing correct words, even when the result is an awkward construction according to the normal rules of language. In this case, the correct word is one which allows members with different interests to see their views reflected in the same standard without necessarily compromising their interests. (Salter, 1995, 45)

6.3 Stabilization of the Reference Model

Literature on the social construction of science and technology provides the concepts of closure and stabilization, which are very relevant to an account of the OAIS development process. Closure occurs when there is wide consensus that a particular problem has been solved. Some particular solution becomes so common that actors generally no longer even consider whether another solution might be desirable. The winning solution becomes so well-established that it becomes simply another part of the environment in which actors work. The arrangement of keys on a typewriter, for example, reached closure at the end of the nineteenth century, when the QWERTY arrangement won out. Design of almost all typewriters and personal computers since then have conformed to that arrangement. Stabilization is similar to closure but has a more limited scope. Whereas closure of a technology holds for a very broad set of actors, stabilization occurs as part of the "development of an artifact within one relevant social group" (Bijker, 1995, p.86). In the broader professional conversations about digital preservation, "various groups will decide differently not only about the definition of the problem but also about the achievement of closure and stabilization" (Bijker, Hughes and Pinch, 1987, p.13).

Within the scope of my study, the relevant stabilization is that which occurred among the set of actors who somehow participated in or contributed to the development of the OAIS. In the development of the Reference Model, certain aspects of the document stabilized within the set of actors involved in the process, while other aspects remained subject to change. The core team members had a large hand in the stabilization of Reference Model elements, but they never entirely controlled the process. "In organized standardization, stabilization is a process that…can only partly be controlled by those who approve a standard." (Schmidt and Werle, 1998, 19)

Finding 3: Over time, the content of the Reference Model stabilized, making changes less likely and more limited in scope.

As explained in Chapters 4 and 5, the Reference Model underwent more dramatic and more frequent changes early in the process. By the later stages, changes still occurred, but they had to overcome the increasing stability of the Reference Model. The two criteria identified in Finding 2 for the addition of content became more stringent over time. One participant explained that there was "an evolution of our ideas in those first couple of years" that involved a great deal of work on collective sensemaking, but after that initial period, "things were pretty stable in terms of what we were aiming at" (I22). It is important to note that stabilization did not mean complete rigidity, nor did it reflect a failure to listen to new ideas. Several interview participants expressed an appreciation for the receptiveness and respect that they received from Sawyer and other Workshop participants, even if their ideas diverged significantly from those of the core team.

The process of stabilization stemmed from at least four factors. First, actors became increasingly both conceptually and practically invested in the Reference Model as it stood at any given time. For many, it began to frame their thinking about the problems and issues associated with digital archiving. For others, it even began to serve as the foundation for design and development activities. Second, there was a desire to complete the OAIS development process, so that it could become an International Standard. Any major revisions jeopardized speedy completion and adoption of the document. Third, some actors recognized the tremendous effort that had already been invested in the Reference Model and did not want to nullify all that hard work,[50] unless a change was very necessary. Based on an objection related to a minor point, "you don't then dive in and want to change everything. I mean, I think Lou and Don have done a fantastic job." (I9) Finally, changes to the Reference Model would impact not only the content of the document but also the large network of actors and other resources

[50] The specific reluctance to alter figures in the Reference Model is consistent with earlier research that suggests individuals can be less likely to introduce changes to a figure that already appears polished and well-formed (Schumann et al, 1996).

surrounding the Reference Model. Enrollment of resources greatly strengthened the OAIS development effort, but it also introduced elements of social inertia based on mutual commitment. Each time resources were enrolled from the environment, they carried with them not only modifications to the form of the Reference Model but also investments in that form. The OAIS development effort involved deliberate co-adaptation between resources and other actors. As both the document and its associated network became better developed, not only did elements of the document become more interdependent, but it was also supported by a large set of actors who have been earlier enrolled and whose enrollment could be called into question if significant changes were introduced.

One participant who entered the process relatively late stated, “you have to remember that by the time a lot of these meetings were taking place, the document itself, the reference model itself was pretty well cooked.” (I19) This individual also commented that the functional model was generally more stabilized than the information model. Another individual whom I interviewed would have liked to see some changes to the terminology used in the Reference Model, but

> it’s like trying to close the barn door after the horse is already gone. Some of this had…not only momentum, sufficient momentum, but the NASA community and maybe some others were determined to push this forward. And so it was a question of getting on the train, or being left at the station. (I21)

New and peripheral participants had to determine which parts of the Reference Model were already considered stabilized by the core team and which were still subject to interpretation, expansion or revision. The core team used several techniques to fend off desires (on the part of them or others) to expand the scope of the Reference Model. First, content perceived as overly detailed could be moved to an Annex, which could inform the reader but was not considered part of the standard itself. For example, the archival scenarios that were located in an Annex to the Reference Model provided details about how the Reference Model could be mapped to particular organizational environments. Some concerns about failure of the Reference Model to speak to some context-specific points could be addressed by adding a scenario that touched on them. A second defense against the packing of numerous additional issues into the Reference Model was the section of the document entitled "Road-Map for Development of Related Standards." One participants commented that this "allow[ed] other agencies and other users to sort of focus on the things they were most interested in, after ours was completed. But by doing that, by making that list, it did sort of say…'Yes, that's all very good, but that should be in this other standard.'" (I22)

Stabilization over the existing contents of the Reference Model played an important part in the initial reaction to a proposed addition of a Preservation Planning entity to the functional model. While they agreed with the importance of preservation to the Reference Model, preservation was something the core members "had always envisioned being in there" already (I2). After all, "the entire thing [Reference Model] was about preservation" (I1) and "the whole archive is all preservation" (I4). If it was necessary to place the activities in one part of the Reference Model, there was "a lot of feeling" that what the NEDLIB project was calling preservation planning could be considered "all part of administration" (I3) within the existing Reference Model. Conceptual resistance was reinforced by a practical interest in completing the standardization process, at a time when “we thought we were drawing to end of the reference model development.” (I3)

> [A couple of individuals] actually went through… we counted in a couple of chapters, how many times the word ‘preservation’ appeared to prove that we don’t need a separate preservation module. And so we basically convinced ourselves and convinced the group that we didn’t need a preservation planning module as a separate distinct activity. And we were pretty much as a group comfortable with and settled upon that we didn’t need Preservation Planning. (I1)

It did not take long for the core team to accept the addition of the Preservation Planning entity, but their initial response is evidence of stabilization around the functional model as it stood at the time. This stabilization was overridden by a recognition that several social groups, whose enrollment could be extremely valuable to the OAIS development effort, did not share the same commitment or understanding of the functional model.

Several interview participants discussed aspects of the Reference Model that they might have preferred to be different, but they accepted the Reference Model without the changes, because it was already too stabilized to undergo major revision. For example, one participant felt that the functional model could benefit from an additional “processing” function, but he accepted the compromise of placing processing activities within the existing Access function, because “the terminology is just too set now.” He did not think that a Processing entity should be added during the five-year review of the Reference Model. “We don’t want the revision to be something that invalidates the original.” (I3)

6.4 Timing of the OAIS Development Effort

> ***Finding 4: A major factor in the success of the OAIS was the timing of the development effort.***

When it comes to reference models, "Their value may be a question of timing." (Libicki et al, 2000). Reference models are high-level conceptual documents, which can serve as "intellectual foundations for subsequent standards." There is a particular period of time during which a reference model can be useful: late enough for there to be sufficient understanding, experience with and recognition of the importance of the problem space addressed by the reference model; but not so late that actors are already wedded to or locked into competing conceptual approaches to the problem space.

6.4.1 No Existing Models

> ***Finding 4.1: Actors within several streams of activity related to digital preservation perceived the need for a high-level model but had not themselves developed one.***

Several streams of activity converged on the OAIS development effort because those streams of activity had not yet developed such a high-level model themselves, but actors involved in those streams perceived the value of having such a high-level model. At the time the OAIS development effort began, "there was no perceived consensus on the needs and requirements for maintaining digital information over the long-term," and "a unifying framework that could fill this gap would be invaluable" (Lavoie, 2004, p.2). "This was an area in which no community had a solution; an area in which multiple communities had a need." "People were floundering. They needed something upon which to base digital efforts." (I1) Several groups had generated "architectures" and other lower-level models, but nothing like the Reference Model (I11). The lack of high-level standards was reflected in the practices of those responsible for the preservation of digital data sets, who were "doing it very ad hoc" and "not defining what the process should be" (I15). When asked why the OAIS had gained such prominence, one interview participant responded bluntly, "There was no reference model for archives." (I16)

6.4.2 Desire to Codify Recent Experience

At the same time that there was no existing high-level model for digital archives and little consistency in language, actors at several data centers and other repositories had learned many lessons in their work. As discussed earlier in Section 1.3.1.5, there were many important developments in earth and space science data archives during the years immediately preceding the initiation of the OAIS development effort.

> ***Finding 4.2: Several actors responsible for digital data now felt they had valuable knowledge related to their recent digital archiving efforts within their own local contexts, which they could use to inform the development of the more general Reference Model.***

One interview participant indicated that, by 1995, he and his coworkers involved in the development of a prototype data archiving system "had just learned a whole lot about what it takes to develop, to build an archive." Participating in the OAIS development effort "was just perfect because it enabled me to utilize a lot of information that I just acquired. A lot of fresh perspective." Development of the Reference Model "provided an opportunity to capture that information." By contributing to the effort, this individual was able to meet the "goal of capturing this information and experience that I had acquired that the tax payers had paid for... Finding a way to convert that to something useful for other people." Participation in the OAIS effort was not simply a uni-direction matter of providing information to others, however. Information sharing occurred in both directions. “It just seemed like a win-win. A two way process of feeding that to a standard that would be useful for other archives and other people. And a source of information and feedback for you know the home team.” (I7)

Another interview participant stated, “I hoped to bring to OAIS all the experience I had negotiating with projects and what are the fundamental characteristics of an archive, what are the interactions you have to have with your suppliers and with your users.” This participant had thought, “Gosh, we’ve learned so much, we’ve got to get this out so everybody else knows what we’ve learned and see, so they don’t have to go through this themselves.” (I20)

Several interview participants suggested that, at the time that the OAIS development effort began, either their own employing agencies or space data centers more generally, were ahead of other communities in the area of digital archiving. This made the possibility of codifying their experience even more desirable, because they could potentially share this codified knowledge with other communities who had a stake in digital preservation but might not yet have much experience or codified knowledge of their own.

Despite this growing body of practical experience and understanding of the functions associated with digital archiving, one essential element was a common vocabulary. Several interview participants discussed the frustrations they had in the past related to inconsistent use of language. Problems had often stemmed from terms that were used so widely and for so many different purposes that it was difficult to determine if they were being used in the same way by different actors. The most common examples were archives/archiving and metadata. One individual commented that “we didn’t even have common terminology within NASA, let alone outside of NASA" (I4). For example, "everyone used the same terms in archiving, but they always meant something different. So many people would have discussions, go home thinking they agreed, and come back discovering they had really been not in agreement." (I3) Conversely, according to another individual I interviewed, "In the early '90s, over and over again I would be having conversations with people and we would spend a whole day arguing over something, only to find out by the next morning that we meant different things and we didn't really disagree." (I7) The combination of pressing need, available expertise, and inconsistent language meant the time was ripe for developing a reference model that could codify and support greater consistency in discussions of digital archiving.

6.5 Defensive Participation

The discussion above, related to Finding 4, suggests important positive reasons why many actors wanted the CCSDS to produce a reference model and why many of them wanted to contribute to the effort. However, several interview participants also expressed more defensive motivations.

> ***Finding 5: One motivation for participation of some actors was to prevent the final product from taking a form that would be detrimental if it were to be applied in their local contexts.***

The literature on standards development discusses such defensive motivations, though many authors have focused on more extreme cases, in which actors participate in the meetings of a standards development organization in order to either slow down or completely prevent the adoption of a standard that those actors see as threatening their business interests. In the development of the OAIS, defensive participation motives took a more subtle form. I saw no evidence of any actors purposely trying to derail the development of the Reference Model. Instead, several actors wanted to ensure that, when the final product was released, it took a form that they found acceptable. This was a particularly important motivation for many of the actors, because they worked in organizational contexts (government entities, government contractors or universities) where it is often considered important to follow existing standards as a matter of principle. In such organizational environments, actors understood that it might be considered obligatory to comply with the final Reference Model, if it were the only model available. In contrast, participation by private sector actors – whose incentives for taking part in SDO activities are tied to advancing their own product lines or services – was quite limited.

One individual, who was not from a space agency, indicated that she "wanted to make sure that if it [the OAIS development effort] was a viable activity, that it went the way it should go." (I1) The concern about detrimental standards was often based on previous experience. One individual indicated, "I'd seen some data standards that I had to deal with, which were just cumbersome to deal with and expensive to deal with… We're still stuck with some of those standards today." He added, "At some point, I knew that work I was doing would be required to meet that standard." So he wanted to ensure that his employer "got it before it got me." (I14) Another participant said, "You can get standards that go through the whole process. And you get them back, and you think, 'How did this ever make it through? This is not at all reflective of what we do. It's going to be impossible for us to work with the standard.'" (I19)

In explaining the motivation for her employer to pay for her involvement in the OAIS development effort, one participant remarked that "their feeling is if you don't get involved, then when they bring us back standards, what's it going to do to us? So they wanted us to be involved, and, in fact, they were happy to pay." She recalled that "they didn't want somebody to coming back with an archiving standard and finding out it would cost us 20 million dollars to implement it. By being involved they felt like they could avoid being out of compliance to what was being developed." (I20)

6.6 Variety of Contributions to the OAIS Development Effort

> ***Finding 6: Contributions to the development of the OAIS took various forms.***

In this study, two of the indicators that I have used for gauging contribution to the OAIS development effort are participation in Workshops and writing/editing tasks. While both indicators are very important for understanding how the process unfolded, they do not tell the whole story. My document analysis and interview data analysis reveal several other important forms of contribution, several of which I have touched upon in the preceding sections of this chapter. I have described the OAIS development effort as an ongoing set of activities by a network of actors who enrolled other actors and resources from the environment. This framing of the process reveals many more contributions than would be visible within a framing of the development of the OAIS as a process that occurred entirely within the confines of the CCSDS and ISO.

This study has revealed numerous contributions in the form of documentary artifacts. Many actors in the environment contributed to the OAIS through the creation of documentary artifacts that could then be drawn into the effort. Other actors provided a valuable service by locating and identifying those relevant documentary artifacts in the environment. Actors submitted formal commentary on the Reference Model in the form of RIDs (Review Item Disposition). Several participants also wrote reports, white papers or comment documents that never became part of formal RIDs but still served as valuable input. Another important form of contribution was mapping the Reference Model concepts to local contexts by writing and submitting the "scenarios" that become part of an annex to the Reference Model. Actors also contributed valuable documentary artifacts specifically for the purposes of administering, documenting and publicizing the OAIS effort. Garrett, for example, developed and maintained an extensive collection of Workshop and other related documents on the Web. This online presence played a pivotal role in the coordination of work on the Reference Model and enrollment of actors from the environment. One participant noted that one of his essential contributions to the process was taking minutes at many of the Workshops. It may be tempting to think of the development of the Reference Model as a purely conceptual endeavor, but contributions such as detailed and accurate minutes "shouldn't be underestimated." (I22)

Other contributions took the form of interpersonal exchanges, rather than tangible documentary artifacts. Many actors provided informal commentary directly to the OAIS editorial team and members of CCSDS Panel 2, or indirectly through an intermediary who was able to attend ISO Archiving Workshops. The enrollment of other actors also played an essential role in the OAIS development effort. This enrollment involved not only conscious recruitment but also more subtle forms such as signaling legitimacy of the effort through participation.

Some actors served as conduits for the contributions of others. This took at least three different forms. First, as part of the formal CCSDS review process, CCSDS Member Agencies or Liaison Agencies sometimes offered to formally convey the comments of actors who were not members of the CCSDS. This was because only CCSDS members could officially offer comment on proposed standards. However, the OAIS editorial team actually accepted and addressed comments as RIDs, even if they were not submitted on behalf of official CCSDS Member or Liaison Agencies. This allowed for ICSTI to play a second type of conduit role. ICSTI is not a CCSDS Member Agency but is instead an international coalition of government agencies, libraries, companies, research councils and professional associations that have strong interests in the publication, management and distribution of scientific and technical information. ICSTI served as a gathering point for comments on the OAIS from its stakeholders and passed the comments along to the OAIS editorial team. Finally, some participants in the OAIS development process saw themselves as representing the interests of a much larger community of allied professionals who were not able to attend the ISO Archiving Workshops themselves. One individual stated, "I was able to serve as information gatherer representative of the community…people would communicate things to me, that I could bring up at the meeting." (I19)

Several research and development projects based their efforts explicitly on the Reference Model. By attempting to apply the Reference Model and then reporting on the results, these projects provided several different things to the OAIS development process. First, they identified existing parts of the Reference Model that were vague, ambiguously, inconsistent, or that could otherwise benefit from refinement. "One of the most valuable things is they tried to use it, and they would come back and say, 'Well, this made sense when we were just talking about it. What does this really mean?'" (I2) Second, they contributed suggestions for extensions or further elaborations on the Reference Model, either through direct addition to the model itself (e.g. addition of the Preservation Planning Entity) or through external guidance documents (e.g. CEDARS guides, NEDLIB adaptations in the DSEP). Finally, application of the Reference Model served as vital acts in the signification and legitimation of the Reference Model, i.e. the social definition of what the Reference Model meant, the purposes toward which it should be applied, and why it was valuable. For example, one interview participant remarked that the work on the NEDLIB project by the KB "was very valuable for promoting it, and saying this really works." (I2) Although adoption of a reference model does not risk the degree of lock-in that could be involved with the adoption of a lower-level standard, the actors who decided to base their project work on the Reference Model long before it had become an International Standard were still taking a "leap of faith" (I19), because there was always the chance that the Reference Model would be significantly different in its final form or that the standardization effort would simply fail to yield an International Standard. The flip side of this risk was the potential to still be able to influence the direction of the standard. "In trying to use it, and in citing the various level of things, they felt like, if they actually used it and there was a problem, they felt like there was still time to influence and kick back in." (I19)

Some authors have pointed out that actors can have varying levels of involvement in standards development efforts. For example, Cargill distinguishes between "observer," "participating" and "contributing" participants (1989, p.84); and Weiss and Toyofuku discuss two types of "free-ridership" (1996). However, I am not aware of any studies that have identified as detailed and diverse a list of contribution forms as I have, including writing; editing; administration of the process; development of various types of external documentary artifacts; identifying and locating relevant artifacts in the environment; mapping the Reference Model to local contexts; informal verbal commentary; enrollment of other actors; serving as conduit for comments of others; representing the interests of those not present at Workshops; testing of the Reference Model, and the refinements and elaborations resulting from the testing; as well as the acts of signification and legitimation enacted through all of the above. Nor am I aware of any study that demonstrates so thoroughly the significant roles that can be played by actors not formally represented in the standards development committee structure. This provides a compelling empirical case for distinguishing between the formal "participants" in a standards development effort and its larger set of "stakeholders," i.e. those with an interest in the final outcome (Moen and McClure, 1994; Moen, 1998).

6.7 Conclusion

The value of documents comes from what at first appear to be two contradictory characteristics: they are both fixed and fluid (Levy, 1994). Some aspects of documents remain consistent enough to allow actors to convey meaning across space and time. However, other aspects of documents remain flexible enough that they can be used and understood in situations dramatically different from the situations in which the documents were created. The degree of fixity or fluidity of a document are not inherent in the artifact itself, but they are instead continuously enacted and re-enacted through a series of social interactions (structuration). Similar processes of structuration are at work in the formation and evolution of genres of documents (Yates and Orlikowski, 1992; Orlikowski and Yates, 1994). The success of the OAIS development effort was based on striking a balance between fixity and fluidity that was both productive and acceptable to a broad set of interested actors. A continuously evolving network of actors and resources developed not just an International Standard document, but also acceptably precise (and acceptably vague) notions of what it means to say one is developing or managing an archival information system and how the genre of "reference model" should be enacted in this context. This study has shown that is not only documents but also the network of resources associated with documents that can benefit from being both fixed and fluid. The development of the OAIS was successful, because the process was fluid enough to enroll a surprisingly diverse set of resources, while also being fixed (i.e. bounded and increasingly stabilized over time) enough that it could (1) generate a coherent document with a clear purpose and scope and (2) and not take any turns so dramatic that they would result in a significant loss from the network of resources that had been enrolled along the way. This is a much more subtle and complicated story than one could tell based on a simple dichotomy between "open" and "closed" standards development.

CHAPTER 7 – REFLECTIONS ON THE RESEARCH PROCESS AND POTENTIAL FOR FUTURE RESEARCH

In addition to the findings presented in the previous chapters, I have learned several valuable lessons about the process of undertaking a multi-method case study related to recent historical events. Along the way, I have also discovered numerous promising areas for future research.

7.1 Lessons from Conducting a Multi-Method Case Study on Recent Events

The timing of conducting case studies involves tradeoffs. Investigating events that have just happened can raise challenges and biases in results. Waiting too long, on the other hand, can limit the availability of interview participants and their ability to convey accurate information due to the limitations of memory discussed in Chapter 3. With the passage of time after transformative events, it can also be "more difficult to extract fresh insights from beneath a new crust of familiarity" (Zuboff, 1988, p.13). One indispensable factor in my study was the triangulation of data sources.

I began with analysis of documentary sources and was surprised by both how fruitful this analysis could be in addressing my research question and how time-consuming it would come to be. This is consistent with Moen's (1998) experience in his case study of the development of Z39.50. He had originally "assumed that interview and observation data would take precedence over the documentary evidence" but instead "found that the former sources of data supplemented the latter" (p.3-30). However, for the reasons I explain in Chapter 3, the documentary sources still provided only one filtered version of what happened. It was important to test and extend my initial findings based on both social network and interview data.

The interviews provided rich perspectives, insights and clarifications, but they were also insufficient data sources on their own. I knew that interview participants would not always be able to recall – several years after the fact – minute details about Workshop conversations, document changes and the contributions of particular individuals. I designed my interview protocol based on what I predicted would be the relative strengths and weaknesses of personal testimony. However, I still did not fully anticipate the extent to which individuals can forget the details of past events. For example, many individuals, particularly those who had not been frequent Workshop participants, had trouble providing precise responses to questions related to issues such as "any times during the workshop(s) when you recall participants having trouble coming to agreement on an issue, concept or word" or "significant examples of terms or concepts that were borrowed from somewhere else as opposed to being invented specifically for the standard." Many interview participants also had difficulty remembering exact dates, names of individuals and the order in which some events occurred. In retrospect, none of the interview participants' struggles with details should be surprising, but they were important reminders for me that those with relatively limited involvement in the development of a standard are not likely to have internalized as many of the details about it as those whose professional identity was intimately connected to the completion and success of the standard.

7.2 Open Questions and Opportunities for Future Research

The last refuge of a social-scientific scoundrel is to call for more research.

- Robert D. Putnam, 1995

7.2.1 Adoption and Diffusion of the OAIS

In this study, I have investigated the process of developing the OAIS Reference Model. One potentially fruitful area of future research relates to the adoption and implementation of the OAIS. Several authors have investigated the diffusion and adoption of standards related to archival description (Duff, 1999; Martin, 1994; Yakel and Kim, 2005; Roth, 2001), but there has been no such study on the diffusion of standards related to digital preservation.

As I explain in Chapter 2, literature on diffusion of innovations and knowledge transfer suggest that time could be a vital factor in adoption and use of the OAIS. Rogers (1995) defines five main steps in an "innovation-decision": learning of an innovation's existence and some of its functions (knowledge); forming a favorable or unfavorable attitude toward it (persuasion); engaging in activities that lead to an adopt/reject choice (decision); putting the innovation into use (implementation); and seeking information that reinforces or refutes the innovation-decision (confirmation). Several studies of knowledge transfer suggest that groups are receptive to learning from others only during specific (often short) periods in the groups' life cycle, with the beginning of that life cycle being a particularly receptive time (Argote, et al, 1990; Baum and Ingram, 1998; Tyre and Orlikowski, 1994).

In the enrollment of actors into the OAIS development process involved aspects of Rogers's first three stages in the innovation-decision process. Contribution to the OAIS effort generally involved some awareness, understanding, and appreciation for the Reference Model. Engagement in writing, editing, Panel 2 decisions, public comment, and formal balloting also conveyed varying degrees of commitment to the Reference Model. Investigation of Rogers's final two stages remains a promising area of future research, given the number of recent digital preservation projects that have professed to adopt, conform to, or make use of the OAIS in their design and implementation efforts.

As I argued in Chapter 2, both Rogers and literature inspired by the technology acceptance model (TAM) gives relatively little attention to those characteristics of the innovation itself that support multiple interpretations, conceptions and purposes. Both of these research traditions tend to treat a given technology/innovation as a discrete entity to be diffused, adopted or rejected based on how a given social entity (individual or group) perceives and interacts with pre-existing characteristics of the technology/innovation. Future research on the adoption and diffusion of the OAIS could provide important insights into the "interpretive flexibility" (Pinch and Bijker, 1984) that may still remain in the work of building archival information systems, as well as the "articulation work" (Star, 1991; Suchman, 1996) required to bring various components together in order to develop and maintain an archival information system in a real-world context.

7.2.2 Timing of Core vs. Peripheral Participation in Standards Development

Early work on the development of the OAIS involved a relatively homogeneous set of actors, who generated a detailed document before it was opened up for much wider input. This meant that the projects (e.g. CEDARS, NEDLIB, PANDORA) that explored use of the Reference Model had a relatively well-developed and understandable volume with which to work. Lex Sijtsma of NEDLIB, for example, indicated in January 21, 1999 that NEDLIB was able to use the Reference Model (then White Book 4) to coordinate its work because the Reference Model is "a complete system." The timing of external project involvement also meant, however, that these peripheral actors entered the process after it had already entered a state of relative stability, i.e. commitment to the document as it currently stood, making any dramatic changes more difficult and less likely than earlier in the OAIS development process.

Future research could further investigate the tradeoff between stabilization and openness by comparing the characteristics of the social networks associated with the development of the OAIS over time and social networks associated with other standards development efforts. Does a high-level conceptual standard such as a reference model require a certain amount of substance and solidity in order to then be successfully taken up by a more diverse set of actors, or is there value to building a more heterogeneous core standards development team from the very beginning of the process?

7.2.3 Professionalization of Digital Preservation Work

An issue closely related to the adoption and diffusion of the OAIS is the role it will play in the system of professions. Abbott (1988) looks at all areas of work as embedded in a history-dependent, socially contextualized "system of professions." Various occupational groups interact, collaborate and compete for positions in a dynamic ecology of work. Abbott presents the concept of "jurisdiction" as "the link between a profession and its work" (p. 20). He contends that "jurisdiction is the defining relation in professional life." Professions develop when jurisdictions become vacant. "Thus events propagate backwards, in some sense, with jurisdictional vacancies, rather than the professions themselves, having much of the initiative" (p. 3). Professional tasks rest on certain "objective foundations": technology; organizations; natural objects and facts; and cultural structures (p. 39). These characteristics of the environment are relatively stable at any given time, but they occasionally undergo dramatic transformations. In those cases, there is a "consequent jostling and readjustment within the system of professions" (p. 33). Contenders for professional claims over the new vacancy attempt "to shape these problems into coherent jurisdictions by creating intellectual processes of diagnosis, inference and treatment" (1995, p. 552). Investigating the activity at the boundaries holds great promise for understanding new professional structures, because "social entities come into existence when social agents tie social boundaries together in certain ways" (p. 555).

One vital component of Abbott's account is that of abstraction, which he characterizes in terms of both the ability to refer to "many subjects interchangeably" and "positive formalism" (p. 102). In fact, he defines professions as "exclusive occupational groups applying somewhat abstract knowledge to particular cases" (p. 8). The ongoing viability and competitive success of a profession rest largely on its ability to articulate, reify, generalize, transfer and apply its knowledge. As the external environment changes, the relevance of this knowledge may shift or even completely disappear.

My study has not addressed the entire system of professions surrounding digital preservation work but has instead looked specifically at the development of the OAIS, which is a set of abstractions intended to guide work on digital archives. Abbott identifies three different arenas of activity in which the dynamics of the system of professions take place: public, legal and workplace. Based on my study, one hypothesis worthy of further investigation is that jurisdictional claims are also negotiated in a fourth arena: extra-institutional groups that cut across existing professional boundaries (in this case, the network of actors and resources surrounding the OAIS development effort). Far from being neutral arbiters of Abbott's first three arenas, a standards development initiative could serve as a site of jurisdiction formation, particularly when the initiative is attempting to generate a high-level conceptual standard, such as a reference models, related to an area of work activity that has not yet been formally mapped out by any particular group of actors. In order to test the above hypothesis, future research could investigate how, and in what ways, the OAIS development effort has contributed to ongoing professionalization activities related to digital preservation, such as individual certification, institutional accreditation, establishment of separate journals, professional associations, conference series and codes of ethics.

In the years preceding the development of the OAIS, there was a trend toward increasing interactions across streams of digital preservation activity, and recent research activities – often based on the OAIS – suggests that the convergence of streams of activity is continuing to increase. It is still an open question whether, however, "digital preservation" will take on the status of one discrete and well-recognized professional jurisdiction. If such a clear jurisdiction does emerge, another open question is what "settlement" will emerge around that jurisdiction. Abbott explains, "The claim to full and final jurisdiction is only one of the possible settlements of jurisdictional dispute" (p.69). There are at least five other forms of settlement: (1) subordination of one under the other; (2) division of labor; (3) "intellectual jurisdiction," in which one profession retains control of cognitive elements but allows others to engage in the work's practice; (4) one profession has advisory control over some aspects of the work; and (5) division according to the nature of the client (p. 69-79). If the OAIS does serve an influential role in the definition of a new jurisdiction, then it may also have dramatic implications for the settlement that emerges around that jurisdiction. The actors involved in the development of the OAIS, its scope, terminology and types of examples it uses could all have “founder effects” upon the future trajectory of the complex adaptive system of professions (Axelrod and Cohen, 1999).

In Abbott’s second and fifth forms of settlement, separate professions can carve off distinct parts of a problem space. They may come to recognize the role and importance of other actors in the same space, but still retain their own set of values, principles and practices associated with the part for which they are responsible. For example, one set of actors could take on the work associated with Archival Storage, while other sets of actors claim responsibility for Ingest, Access, Data Management, Preservation Planning, Administration and Management, respectively (Abbott’s settlement 2). Alternatively, separate professional communities could each take on all of the OAIS functions entirely by themselves, but differentiate themselves based on the types of materials they manage and the Designated Communities they serve (Abbott’s settlement 5). If the history of physical artifact curation is any indication, then the most likely arrangement in the digital environments will be some combination of Abbott’s second and fifth settlements.

7.2.4 Status and Trajectory of OAIS Language

The terminology and concepts in the Reference Model were not entirely borrowed from any one field, discipline or profession. Instead, the Reference Model is a conglomeration of pieces from various places as well as many invented specific for the document. The result is "a common language and concepts for different professional groups involved in digital preservation and developing archiving systems" (Beagrie, 2003, p. 45). The OAIS is an artifact that supports interaction in the "trading zone" that resides between different streams of activity (Galison, 1997). Actors from different streams of activity can agree to use the terms and concepts from the OAIS in order to share ideas and coordinate their work, even if they still hold dramatically different worldviews, values or assumptions of their own responsibilities. When a language is created specifically for interaction in a trading zone, an open question is whether that language continue to serve as a pidgin (considered to be an artificial second language by all actors involved) or it will become a creole (adopted by the next generation of speakers as their native language or one of their native languages). Pidgin languages are simple and relatively undeveloped. They only need to be complicated enough to support the fairly bounded set of interchanges that occur in the trading zone. Creoles, however, are languages that speakers "live with." They must be sophisticated and detailed enough to address the diverse and unpredictable set of activities that occur in everyday practice. The language embedded in the OAIS could find its place in the ecology of digital preservation language as a pidgin used only by funding agencies, strategic planners, system architects, contractors, consultants and others who actively work at the boundaries between streams of activity. Like many pidgins, OAIS language could also fade away entirely, replaced by some other mechanism for working within the digital preservation trading zone. However, a third possible path is that of OAIS language as creole, serving as the primary way that future generations of at least some set of actors within the system of professions talks about what it does. Such a creole would have to evolve, in order to address any number of problems and situations that no one has yet predicted. I cannot claim to know which of those three possible futures will come to pass, but I am certain that the OAIS will take a significantly different path than would have been possible if it had simply served as a standard to codify the natural language of NASA. It is a great testament to the many devoted individuals and organizations involved in the OAIS development process that I can even reasonably pose such questions.

APPENDICES

Appendix 1 – Detailed Timeline of Major OAIS Development Events

Date	Event	Description/Type
April 15, 1994	Gael F. Squibb of NASA Jet Propulsion Laboratory presented three new work item proposals to ISO TC 20 / SC-14, including "Space Systems – Archiving space data"	Document
October 27, 1994	Email message from Robert Stephens to Don Sawyer (among others) noting that SC-14 requested SC-13 to consider pursuing three new work packages, including "archiving space data."	Document
November 21, 1994	Preliminary minutes of the CCSDS Management Council, distributed through email, indicating "CCSDS resolves to accept the request…by generating a new work package…assigned to Panel 2"	Document
April 24, 1995	Don Sawyer, "Background Material and Proposal for Addressing a NAS-Led US and International Archiving Standards Effort," Draft 1.1, proposed for NASA management. Warns of the preservation risks associated with NASA's "attempts to privatize its data infrastructure" and current computing trends "toward highly distributed archiving environments." "NASA has the timely opportunity to lead the newly formed Archiving Standards task…" Sawyer proposed 3 phases: (1) develop reference model, (2) "identify a list of available (or missing) standards" at "each functional area/interface," and (3) "develop any missing standards that were felt to be cost-effective" and prototype.	Document
April 25, 1995	Don Sawyer, "Comments on SC 13/14 N36 – Archiving Task: NASA Response to Greenbelt Action Item 39": "…we believe that to fulfill it properly will take a significant commitment from the participating agencies…[and] will have to be a separate Panel 2 activity with new resources devoted to it." "…we should prepare an ISO New Work Proposal on this subject while we are in Toulouse so we can get it to the Management Council when they meet in mid-May."	
May 1995	ISO Proposal for a New Work Item: Archive Model and Services for Space and Related Data (posted to Web, June 10,	Document

	1995)	
May 1995	International effort organized under CCSDS Panel 2	Activity
September 14, 1995	First public call for participation in First US Workshop	Document
September 1995	Lou Reich and Don Sawyer, "Digital-Archiving Information Services Reference Model"	Document
October 11-12, 1995	First US Workshop	Meeting
October 26-27, 1995	First ISO TC20/CCSDS Panel 2 Archive Standards meeting (First International Workshop)	Meeting
December 19, 1995	Lou Reich and Don Sawyer, "Archive Reference Model, Version 2"	Document
December 19-20, 1995	Second US Workshop	Meeting
March 11, 1996	Lou Reich and Don Sawyer, "Reference Model for Archival Information Services, Version 3"	Document
March 19-20, 1996	Third US Workshop	Meeting
March 20-21, 1996	First French Workshop (National Workshop on The Long Term Archival of Digital Scientific and Technical Data)	Meeting
April 22, 1996	Lou Reich and Don Sawyer, "Reference Model for Archival Information Services, Version 4.0" (PAS/96/P2)	Document
April 29-30, 1996	Second International Workshop	Meeting
July 5, 1996	Lou Reich and Don Sawyer, "Reference Model for Archival Information Systems, Version 5.0"	Document
July 10-11, 1996	Fourth US Workshop	Meeting
September 23, 1996	Lou Reich and Don Sawyer, "Reference Model for an *Open* Archival Information System, Version 6.0"	Document
October 2-3, 1996	Fifth US Workshop	Meeting
October 25, 1996	Lou Reich and Don Sawyer, "Reference Model for an Open Archival Information System, Version 7.0" (MUN/96/P2/N11)	Document
November 4-5, 1996	Third International Workshop	Meeting
January 6, 1997	Don Sawyer and Lou Reich, "Reference Model for an Open Archival Information System, Version 8.0"	Document
January 8, 1997	Sixth US Workshop	Meeting
April 10, 1997	Don Sawyer and Lou Reich, *Reference Model for an Open Archival Information System (OAIS)* (White Book, Issue 1) - CCSDS 650.0-W-1	Document
April 16-17, 1997	Seventh US Workshop	Meeting
May 1997	Submitted White Book 1.0 to ISO as Committee Draft	Activity
May 12-14, 1997	Fourth International Workshop	Meeting

July 5, 1997	Don Sawyer and Lou Reich, *Reference Model for an Open Archival Information System (OAIS)* (White Book, Issue 1.1) - CCSDS 650.0-W-1.1	Document
July 16-17, 1997	Eighth US Workshop	Meeting
September 10, 1997	First UK Workshop	Meeting
September 29, 1997	Don Sawyer and Lou Reich, *Reference Model for an Open Archival Information System (OAIS)* (White Book, Issue 1.2) - CCSDS 650.0-W-1.2	Document
September 30 – October 1, 1997	Ninth US Workshop	Meeting
October 15, 1997	Don Sawyer and Lou Reich, *Reference Model for an Open Archival Information System (OAIS)* (White Book, Issue 2) - CCSDS 650.0-W-2.0	Document
October 27-29, 1997	Fifth International Workshop	Meeting
January 28-30, 1998	Tenth US Workshop	Meeting
April 1-3, 1998	Eleventh US Workshop	Meeting
April 15, 1998	Don Sawyer and Lou Reich, *Reference Model for an Open Archival Information System (OAIS)* (White Book, Issue 3) - CCSDS 650.0-W-3.0	Document
May 13-16, 1998	Sixth International Workshop	Meeting
June 22-26, 1998	Digital Archive Directions (DADs) Workshop	Meeting
September 16-18, 1998	Thirteenth US Workshop	Meeting
September 17, 1998	Don Sawyer and Lou Reich, *Reference Model for an Open Archival Information System (OAIS)* (White Book, Issue 4) - CCSDS 650.0-W-4.0	Document
October 26-30, 1998	Seventh International Workshop	Meeting
December 1998	At a meeting in Paris, the NEDLIB project team decided to adopt OAIS as a basis for design.	Related Project
December 16-17, 1998	Fourteenth US Workshop	Meeting
April 21, 1999	Don Sawyer and Lou Reich, *Reference Model for an Open Archival Information System (OAIS)* (White Book, Issue 5) - CCSDS 650.0-W-5.0	Document
May 11-13, 1999	Eighth International Workshop	Meeting
May 1999	*Reference Model for an Open Archival Information System (OAIS)* (Red Book, Issue 1) - CCSDS 650.0-R-1 (Draft Recommendation adopted as ISO/DIS 14721)	Document
June 10-11, 1999	Fifteenth US Workshop	Meeting
October 1999	Council on Library and Information Resources, Digital Library Foundation, and	Meeting

	Coalition for Networked Information convened publishers and librarians to discuss archiving of electronic journals, and CLIR staff extracted minimum requirements from the OAIS.	
October 13-15, 1999	Archival Workshop on Ingest, Identification, and Certification Standards (AWIICS)	Meeting
November 9-10, 1999	Ninth International Workshop	Meeting
May 12-15, 2000	Tenth International Workshop	Meeting
July 19-20, 2000	Seventeenth US Workshop	Meeting
September 14-15, 2000	Eighteenth US Workshop	Meeting
November 1-3, 2000	Eleventh International Workshop	Meeting
February 20-23, 2001	Nineteenth US Workshop	Meeting
April 10-11, 2001	Twentieth US Workshop	Meeting
April 20, 2001	*Reference Model for an Open Archival Information System (OAIS)* (Red Book, Issue 1.1) - CCSDS 650.0-R-1.1	Document
May 14-16, 2001	Twelfth International Workshop	Meeting
June 6, 2000	National Library of Australia issued comments on the OAIS (CCSDS 650.0-R-1)	Document
June 14, 2001	*Reference Model for an Open Archival Information System (OAIS)* (Red Book, Issue 1.2) - CCSDS 650.0-R-1.2	Document
July 2001	*Reference Model for an Open Archival Information System (OAIS)* (Red Book, Issue 2) - CCSDS 650.0-R-2 (Draft Recommendation adopted as ISO/DIS 14721.2	Document
July 2001	Red Book, Issue 2 delivered to ISO and CCSDS Secretariats for public review	Document
July 20 – October 12, 2001	Period for member and observer agencies to submit comments on Red Book, Issue 2	Review Period
October 19, 2001	“Digital Curation” workshop in London, which aimed to “raise the profile of the Open Archival Information System Reference Model (OAIS) standard in the UK and share practical experience of digital curation in the digital library sector, archives, and e-sciences.”	Meeting
October 22-24, 2001	Thirteenth International Workshop	Meeting
January 2002	*Reference Model for an Open Archival Information System (OAIS)* (Blue Book, Issue 1) - CCSDS 650.0-B-1, adopted as ISO 14721:2002	Document
February 2002	RLG announced formation of OAIS-Implementers electronic mailing list.	Activity
April 3-5, 2002	Fourteenth International Workshop	Meeting

May 2002	SAE announced they would not longer serve as secretariat for some TC 20 activities, including SC 13.	Reorganization
September 30 – October 2, 2002	Fifteenth International Workshop	Meeting
December 2002	*Producer - Archive Interface Methodology Abstract Standard*. Draft Red Book (Panel Draft of Draft Standard). Draft Issue 2 - CCSDS 651.0-R-1 (draft)	Document
February 24, 2003	International Standard Published - Space data and information transfer systems – Open archival information system – Reference model (ISO 14721:2003)	Document
March 30 – April 8, 2003	Sixteenth International Workshop	Meeting
September 10 – October 3, 2003	Seventeenth International Workshop	Meeting

Appendix 2 – Selective Timeline of External Presentations by OAIS Team

Date	Event	Stage
October 18, 1995	Don Sawyer, "Status of US Contribution to ISO Archive Standards" to Tape Head Interface Committee (THIC)	1
1997 (some time before Fourth International Workshop)	Research Libraries Group	2?
1997 (some time before Fourth International Workshop)	NSSDC	2?
1997 (some time before Fourth International Workshop)	SOMO Data Archiving and Distribution Panel	2?
August 1997	"Developing an ISO Reference Model for an Open Archival Information System," Don Sawyer and "Guiding the Development of an Open Archival Information System," Bruce Ambacher at Society of American Archivists Annual Meeting	3
September 22, 1997	"Presentation on the scope and progress of CCSDS to define the ISO reference model for an OAIS," CEOS Archiving Task Team Meeting, Claude Huc	3
June 1-5, 1998	"CCSDS Standards: A Reference Model for an Open Archival Information System (OAIS)," Nestor Peccia, David Giaretta, Don Sawyer, Lou Reich, Patrick Mazal, Yoshio Inoue, and Eduardo Whitaker Bergamini at SpaceOps Conference	3
July 9, 1998	Don Sawyer, Lou Reich, "Status of the ISO Reference Model for an Open Archival Information System (OAIS)" at National Association of Government Archivists and Records Administrators (NAGARA) Annual Meeting	3
February 19, 1999	Don Sawyer, "ISO 'Reference Model For an Open Archival Information System (OAIS)'" to USDA Digital Publications Preservation Steering Committee	3
March 15, 1999	Lou Reich and Don Sawyer, "ISO 'Reference Model For an Open Archival Information System (OAIS)'" at IEEE/GSFC Mass Storage Symposium	3
September 8-10, 1999	Don Sawyer, Lou Reich, Ben Kobler and John Garrett, "Digital Information Preservation Perspectives," EU-US Workshop on Large Scientific Databases	4
June 19, 2000	Don Sawyer and Lou Reich, "The Open Archival Information System: The Value and Process of Developing a Reference Model" at CENDI Meeting (interagency working group of senior Scientific and Technical Information managers from nine U.S. federal agencies)	4
June 19-23, 2000	Don Sawyer, Lou Reich, David Giaretta and Nestor Peccia,	4

	"Application of Long Term Preservation Concepts and Requirements to Mission Archives," SpaceOps 2000 Conference	
October 15-19, 2000	Lou Reich and Don Sawyer, "ISO Open Archival Information Systems Reference Model: Concepts and Current Status" at 17th International CODATA Conference	4
October 24, 2000	Don Sawyer and Lou Reich, "The Open Archival Information System: A Model for Preserving Digital Information" at Federal Deposit Library Conference	4
October 30, 2000	Nestor Peccia, Gianmaria Pinna, Don Sawyer, Lou Reich, David Giaretta, Patrick Mazal and Claude Huc, "The Open Archival Information System The Open Archival Information System Application of long term Preservation Application of long term Preservation concepts and requirements to Mission concepts and requirements to Mission Archives" to the Future Space Environment Data Systems Round Table	4
December 15, 2000	Lou Reich, Donald Sawyer, Claude Huc, "ISO Open Archival Information Systems Reference Model: Concepts and Current Status" at NEDLIB Workshop	4
April 26, 2001	David Giaretta presentation about the OAIS to the Object Management Group (OMG) Space DTF (Domain Task Force)	4
June 16, 2001	Alan Wood, Don Sawyer, and Lou Reich, "Reference Model for an Open Archival Information Systems (OAIS): Overview and Current Status" at American Library Association Annual Conference	4
December 11, 2001	Federal Library and Information Center Committee (FLICC) and CENDI joint symposium entitled "Managing and Preserving Electronic Resources: The OAIS Reference Model." Included presentations by Don Sawyer and Lou Reich.	4
February 17, 2002	Don Sawyer and Lou Reich, "Framework for Digital Archiving: OAIS Reference Model" at American Association for the Advancement of Science (AAAS) Symposium	5
March 20, 2002	Don Sawyer and Lou Reich, "Framework for Digital Archiving: OAIS Reference Model" at Langley Research Center	5
April 19, 2002	Don Sawyer, featured speaker at "The OAIS Imperative: Enduring Record or Digital Dust?" hosted by Meg Bellinger as part of OCLC Institute videoconference series "Steering by Standards" at Stanford University Libraries, also speaking were Bruce Ambacher and MacKenzie Smith	5
May 20-21, 2002	Donald Sawyer, Lou Reich and Thierry Levoir, "Framework for Digital Archiving: OAIS Reference Model" at CODATA Workshop on Archiving Scientific & Technical (S&T) Data	5
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May 28, 2003	John Garrett, "Open Archive Information Systems Standards Efforts," 5th Annual Raytheon Science Data Centers Symposium	5+
November 15-16, 2004	Don Sawyer and Lou Reich, "Reference Model for an Open Archival Information System (OAIS)" at Partnerships in Innovation - Serving a Networked Nation	5+

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Appendix 4 – Interview Instrument

Institutional Reasons and Resources for Participation

1. Did a specific person ask you to take part in the workshop(s)?

1a. If so, who?

2. Who paid to send you to the workshop(s)?

3. Why do you think [actor named in 1] sent you?

4. [If not answered in 3] Why do you think [actor named in 2] paid for you to take part?

Personal Reasons for Participation

5. Do you recall how and when you first heard about the OAIS?

6. From a more personal point of view, why did you want to take part in the workshop(s)?

7. [Follow-up – only ask if not covered in 6] What did you hope to get out of taking part in the workshop(s)?

8. [Follow-up – only ask if not covered in 6] What connections did you see between participation in the workshop(s) and your job?

9. [Follow-up – only ask if not covered in 6] What connections did you see between participation in the workshop(s) and the problems faced by your profession (the profession(s) that you identified earlier)?

10. Think again about your goals and objectives for taking part in the OAIS workshop(s). Where there any cases in which you changed those goals and objectives based on discussions with other meeting participants?

11. [Ask only of participants who stopped attending workshops before the OAIS reached Blue Book status.] Why did you stop taking part in ISO Archiving Workshops?
Personal Resources and Contribution

12. What skills and expertise do you think you brought to the process?

13. What previous experience did you have in standards development work?

14. What skill and expertise do you think other participants brought to the process?

Substance of the OAIS Discussion

I'd like to ask you some questions about the discussions that took place in the meeting(s) in which you took part. I've sent you some pointers to documentation from the meeting(s), which hopefully will help to refresh you memory somewhat. I realize it was several years ago, and this isn't intended to be a test of your memory. Please just answer based on what you recall. It's perfectly acceptable to let me know if there are things you don't remember very well.

Closure vs. Openness

15. Please tell me about any times during the workshop(s) when you recall participants having trouble coming to agreement on an issue, concept or word?

16. Do you recall any times when you reached quick consensus on a decision related to the content of the reference model (i.e. there was no need for negotiation or argument)?

Information Reuse

17. At the workshop(s) in which you took part, of the terms or concepts under discussion for inclusion in the OAIS, can you think of any significant examples of ones that were borrowed from somewhere else as opposed to being invented specifically for the standard?

18. Can you think of terms or concepts discussed at the workshop(s) that were invented specifically for the standard?

Perception of Outcomes

So far, we've been talking about the OAIS Reference Model in the form it took when you attended the workshop(s). Now I have a few questions about final document (Blue Book) that has been published as an ISO standard.

19. What connections do you see between the OAIS Reference Model and your job?

20. What connections did you see between the OAIS Reference Model and the problems faced by your profession (the profession(s) that you identified earlier)?

Wrap Up

21. Is there anything else you would like to tell me about the OAIS or your participation in the development process?

Appendix 5 – Interview Background Information Form

Name:
Date:

Please provide the following background information before taking part in the interview. It should take approximately 5-10 minutes. Thank you again for your participation!

Employer:

E1. For what organization did you work when you took part in the ISO Archiving Workshop(s)?

E2. What was your job title?

E3. How long had you been working for that organization?

E4. How long had you been working under the job title identified in question E2 above?

E5. If you have changed employers or job titles since you first attended an ISO Archiving Workshop, please indicate when and to what employer(s) you switched?

Professional Affiliation:

P1: If you were to place a name on the profession(s) to which you belong, what name(s) would that be? (If you list more than one, please provide them in rank order – from the name that most closely matches your work to the one that least closely matches.)

P2: Please list your educational degrees and the subject areas in which you received them.

P3: Please list any professional certifications you have received

P4: Please list the professional association or organizations to which you belong

P5: What were the latest three conferences you attended?

P6: What conferences do you attend regularly?

P7: Please list up to the three journals or other professional publications (in rank order) that you most often read

Appendix 6 – Major Organizational Actors in the OAIS Development Process

This appendix provides brief descriptions of the major organizational actors involved in the OAIS development process. It begins with the ISO and CCSDS, which were the two standards development organizations with direct oversight for the progression of the Reference Model through its phases of development: from draft versions to White Books, to Red Books, to Blue Book and finally to International Standard status. I then provide a general characterization of the organizational actors that were most actively involved in ISO Archiving Workshops.

International Organization for Standardization (ISO)

Founded in 1947, the ISO is a non-governmental organization responsible for standardization at a global level. Member bodies of ISO are organizations that represent the standardization activities in their respective countries. Responsibility for information technology standardization is shared by the ISO and International Electrotechnical Commission (IEC), and it is nominally under the purview of ISO/IEC Joint Technical Committee 1 (JTC 1), which was formed in 1987. The OAIS, however, falls under Technical Committee 20 (Aircraft and Space Vehicles), Subcommittee 13 (Space Data and Information Transfer Systems). The formal Secretariat for TC 20/SC 13 is the American National Standards Institute (ANSI), and it is administered by NASA. The CCSDS is a liaison organization to TC 20/SC 13. SC 13 and SC 14 are currently undergoing an effort to separate from TC 20 and form a new separate Technical Committee dedicated specifically to space systems (TC-999). The ISO places standards within a controlled taxonomy called the International Classification for Standards (ICS).

The OAIS falls within ICS 49.140, where 49 designates “aircraft and space vehicle engineering,” and 140 stands for “space systems and operations.”

A new standardization activity is initiated when a member proposes a new work item. If ISO accepts the proposal, development of the standard or set of standards is assigned to a technical committee. Administration of each technical committee is the responsibility of its Secretariat, which is one of the member organizations. Technical committees can also be divided into subcommittees and still further into working groups. A technical committee works on a standard document until they reach consensus on a draft agreement, which is then circulated as a Draft International Standard (DIS) to ISO's national member bodies for comment and balloting. Many national member bodies have their own public review procedures, in order to solicit feedback from stakeholders within their own countries, which they then take into account when formulating their position national position on the DIS. If the vote on a DIS is favorable, the document, with possible revisions, is again circulated for ISO national member body vote, this time as a Final Draft International Standard (FDIS). A positive vote on the FDIS results in publication as an International Standard. Alternatively, if the vote on a DIS results in 100% approval from the member bodies voting, the DIS can be approved for direction publication as an International Standard without changes (other than editorial corrections) and forgo the final FDIS vote. This was the case with the OAIS, which was not subject to a final FDIS vote, after it received an 8-0 vote as a DIS.

Consultative Committee for Space Data Systems (CCSDS)

The CCSDS was established in 1982 “to provide a forum for space agencies interested in mutually developing standard data handling techniques to support space research, including space science and applications, conducted exclusively for peaceful purposes." There are currently twenty-nine space agencies that serve as Members or Observers of the CCSDS. Administration of the CCSDS is through NASA in Washington, DC. At the time of the development of the OAIS, the CCSDS was composed of four technical panels. Panel 2, Standard Information Interchange Processes, was responsible for the development of the OAIS. The primary products of the CCSDS are called Recommendations, which are intended "to guide the internal development of standards within each of the participating agencies." The CCSDS also generates Reports, which provide "additional material to support implementation of the Recommendations." At the beginning of the 1990s, the CCSDS entered its liaison cooperative arrangement with ISO TC 20, SC 13 described above. Under this arrangement, CCSDS can submit its Recommendations to SC 13, which then advances them through the ISO review and voting process

Overview of Organizational Actors with Most Workshop Participation

This section provides a general characterization of the organizational actors that were most actively involved in ISO Archiving Workshops (each having 10 or more participation acts). Each time an organizational actor is first mentioned, its name is in bold text.

The most central organizational actor in the OAIS development process was the **National Aeronautics and Space Administration (NASA)**, which served as the secretariat for both ISO SC 13 and the CCSDS; employed the leader of the ISO Archiving Work Package (Sawyer), and was responsible for funding the participation (either as employees or through contracts) of close to a quarter of all the individuals who took part in ISO Archiving Workshops and funding the participation of the majority of the core US team. NASA was formed in 1958 as a confederation of several pre-existing institutions and organizational cultures, and this internal diversity has been a defining feature of the agency throughout its history (McCurdy, 1993; Rosenthal, 1968; Wallace, 1999). NASA operates ten field centers, including the **Goddard Space Flight Center (GSFC).**

Established in 1959 as NASA's first space flight center, GSFC now occupies several dozen buildings both on its main campus in Greenbelt, Maryland and its Wallop Island facility in Virginia. GSFC has been involved in the management of large-scale data sets for several decades (Rosenthal, 1968; Wallace, 1999). It has also been a key organizational actor in the arena of mass storage systems and technology (MSST). GSFC began a series of conference on MMST in 1991, which has been held in conjunction with the IEEE Conference on Mass Storage Systems since 1998. GSFC is an organization dedicated to scientific research and development, and its data management environment reflects this. From its early history, GSFC activities have generally been organized around projects (Rosenthal, 1968), which is still true today (Senserini et al, 2004).

Consistent with NASA's overall organizational structure and culture, it has addressed data management in a relatively decentralized manner. One example of NASA's distributed approach is the **Life Sciences Data Archive (LSDA)**, which is composed of a set of LSDA Nodes operated and maintained by those NASA Centers that have life sciences activities. In addition to nodes at Kennedy Space Center (KSC) on Merritt Island in Florida, and Johnson Space Center (JSC) in Houston, Texas, the Ames Research Center (ARC) at Moffett Field, California, also maintains a node, which is often indicated in the OAIS Workshop documentation as the **Ames Life Sciences Data Archive**.

Despite its generally distributed data management architecture, NASA does provide elements of centralized guidance and archiving services through the **National Space Science Data Center (NSSDC)**, established in 1966 as NASA’s “permanent archive” for data from space science missions. NSSDC is sponsored by NASA's Office of Space Sciences and is part of the Space Science Data Operations Office (SSDOO) at GSFC in Greenbelt, MD. According to the NSSDC’s web site, its “staff consists largely of physical scientists, computer scientists, analysts, programmers, and data technicians.”[51] The NASA/Science Office of Standards and Technology (NOST) is located at the NSSDC. NOST leads NASA's participation in CCSDS Panel 2. Donald Sawyer, who led the effort to develop the OAIS, is currently both the head of NOST and acting head of the NSSDC.

Two laboratories with close ties to NASA are the **Jet Propulsion Laboratory (JPL)** and **Applied Physics Laboratory (APL)**. JPL is managed by the California Institute of Technology in Pasadena, but it is also a federally funded research and development center (FFRDC), which has a long-standing arrangement to conduct work for NASA. APL, located in Laurel, Maryland, is a research and development division of the Johns Hopkins University. It conducts research and support for NASA, as well as the Department of Defense and other government agencies.

Several private-sector NASA contractors were also actively involved in the ISO Archiving Workshops. One such organizational actor was **Hughes STX**, a subsidiary of

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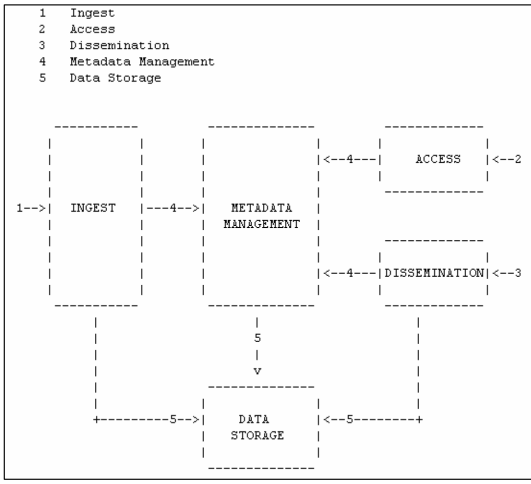
[51] http://nssdc.gsfc.nasa.gov/about/about_nssdc.html

Hughes Electronics Corporation. Hughes STX was formed when Hughes – itself owned by General Motors (GM) since 1985 – acquired the ST Systems Corporation (STX) in 1991. Raytheon then bought STX from Hughes to form **Raytheon STX** in 1997, which became part of the Raytheon Systems Company (RSC). The primary customer of Raytheon STX was NASA but it also did a substantial portion of its work for NOAA. RSC later reorganized, and Raytheon STX was merged with some other units to become Raytheon Information Technology and Scientific Services (ITSS). Another NASA contractor to participate in many Workshops was the **Computer Sciences Corporation (CSC),** a very large information technology consulting and services company. Founded in 1959, CSC has had contracts with NASA since 1961 and has subsequently had billions of dollars of business with the space industry. CSC maintains offices in Greenbelt, immediately adjacent to the GSFC. **Lockheed-Martin Corporation** also sent individuals to many Workshops. With headquarters in Bethesda, Maryland, Lockheed-Martin is one of the world's largest aerospace, defense and information technology companies. It was formed when Lockheed and Martin Marietta merged in 1995. In 1998, under an arrangement called the Consolidated Space Operations Contract (CSOC), all of NASA's space operations contracts were consolidated under Lockheed-Martin. Another organizational actor represented at many workshops was **SGT, Inc.**, an aerospace engineering and technical services company, headquartered in Greenbelt. SGT was founded in 1994 and has held contractors with several NASA entities and other NASA contractors (including CSC, Lockheed Martin and Raytheon), as well as other government agencies and corporations.

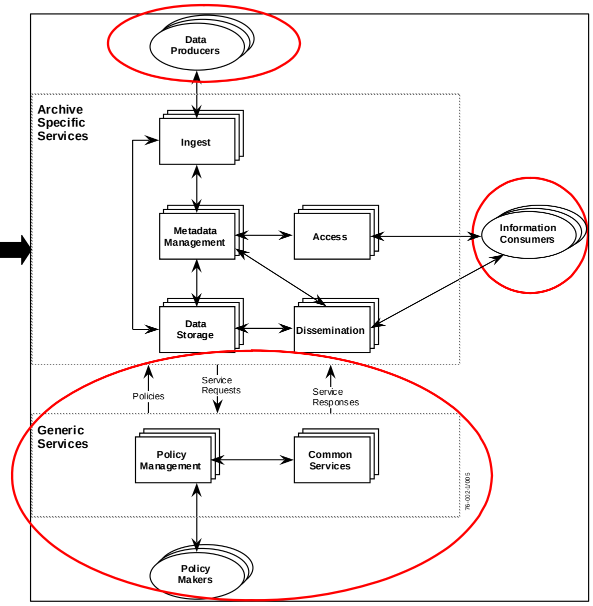
Several CCSDS Member Agencies in Europe were also regular participants in ISO Archiving Workshops. By far the most active among them was the **Centre National d'Etudes Spatiales (CNES)**, the French Space Agency. Created in 1961, CNES is a state-owned organization, headquartered in Paris. Its main space center is Centre Spatial Guyanais in French Guiana, which it operates in cooperation with the **European Space Agency (ESA)**. CNES also runs several space centers in France. Like CNES, the ESA has its headquarters in Paris. The ESA is an inter-governmental organization established in 1975. It currently has 16 member states. Several countries that are members of the ESA also have their own national space agencies, including CNES in France and the **British National Space Centre (BNSC)** in the UK. The BNSC is a consortium of 11 government departments and research councils, formed in 1965 to coordinate civil space activities in the UK. One of the BNSC members is **Rutherford Appleton Laboratory (RAL)**, located in Oxfordshire, UK, is a scientific laboratory created through merger of Rutherford High Energy Laboratory, Atlas Laboratory and Appleton Laboratory in the 1970s. RAL provides space research, development, and test facilities. Since 1995, RAL has operated within the structure of the UK government-run Council for the Central Laboratory of the Research Councils (CCLRC).

The one continuously represented organizational actor in ISO Archiving Workshops was the U.S. **National Archives and Records Administration (NARA)**. The National Archives was founded in 1934, moved into the General Services Administration (GSA) and renamed the National Archives and Records Service (NARS) in 1949, and then became NARA, an independent agency, in 1985. The headquarters of NARA is in Washington, DC. It opened a major new facility in College Park, Maryland in 1994, known as Archives II. NARA administers a system of nine regional records facilities and eleven Presidential libraries across the country. For most of its history NARA has focused the bulk of its resources on management, preservation and access to physical analog records. For several decades, it has taken custody of, and learned valuable lessons from the management of, a small but growing number of electronic records (Ambacher, 2003). The Center for Electronic Records (CER) was established within NASA in 1988 to address issues related to the management and preservation of electronic government records. NARA launched a project in 1998 called Electronic Records Archives (ERA), which aims to preserve and provide access to a much larger number and broader diversity of electronic records than it has in the past.

Appendix 7 – Graphical Chronology of Changes to OAIS Functional Model



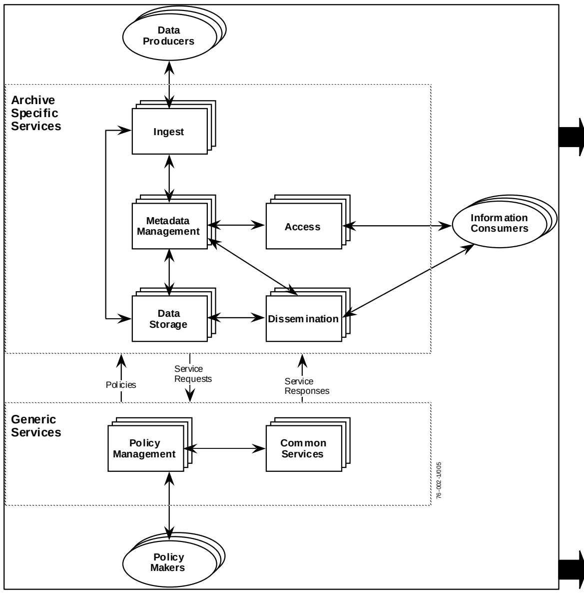
Version 1 (Sept 14, 1995) - Archival Information Services Interfaces and Relationships

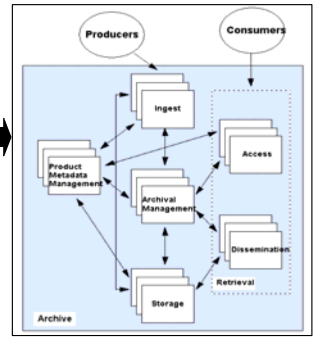


Version 2 (Dec 19, 1995) - High-Level Architecture of Digital Archive Reference Model

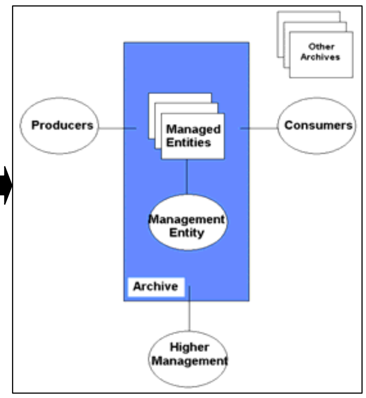
Added:
- Producers and Consumers
- Generic Services
- Policy Makers

Figure 7 - Functional Model: Version 1 to Version 2





Version 3 (March 11, 1996) – No Figure Label

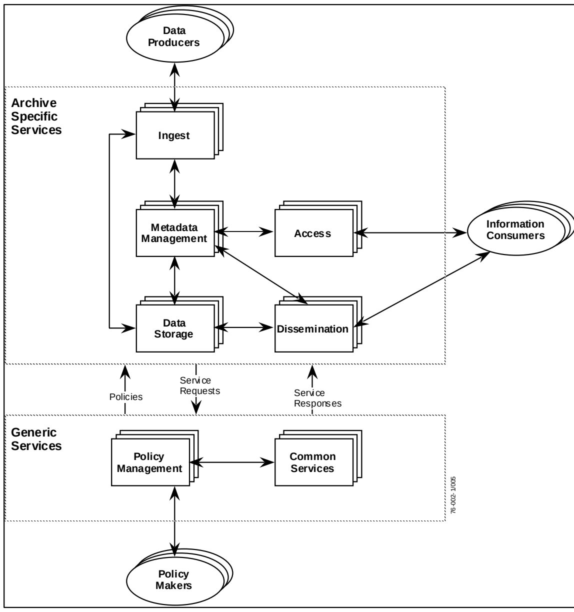


Version 2 (Dec 19, 1995) - High-Level Architecture of Digital Archive Reference Model

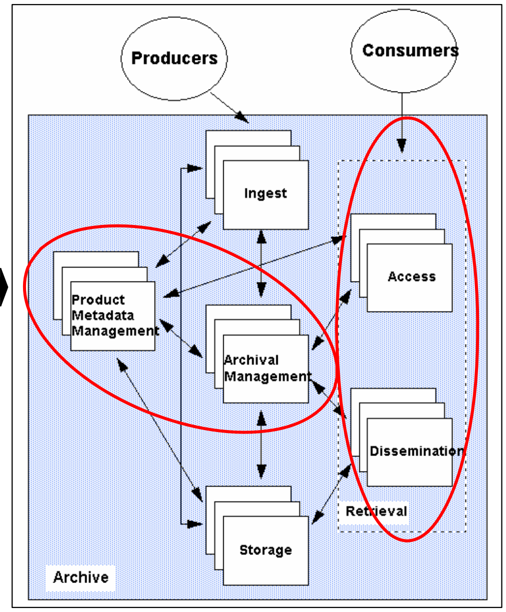
- “High-Level Architecture” Label Removed
- “Archive Environment View” Split out as Separate Figure

Version 3 – Archive Environment View

Figure 8 - Functional Model: Version 2 to Version 3



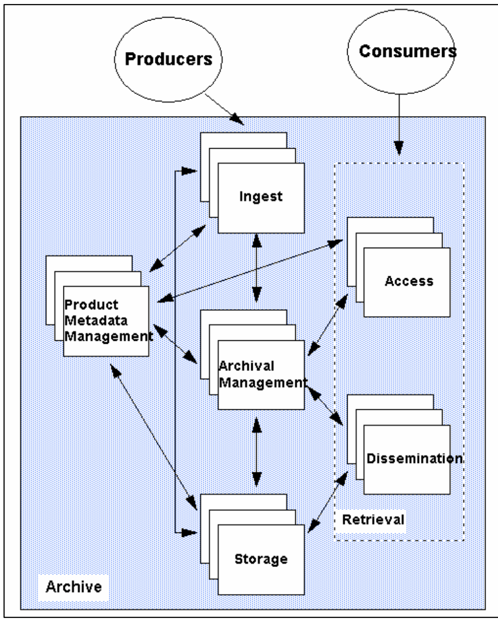
Version 2 (Dec 19, 1995) - High-Level Architecture of Digital Archive Reference Model



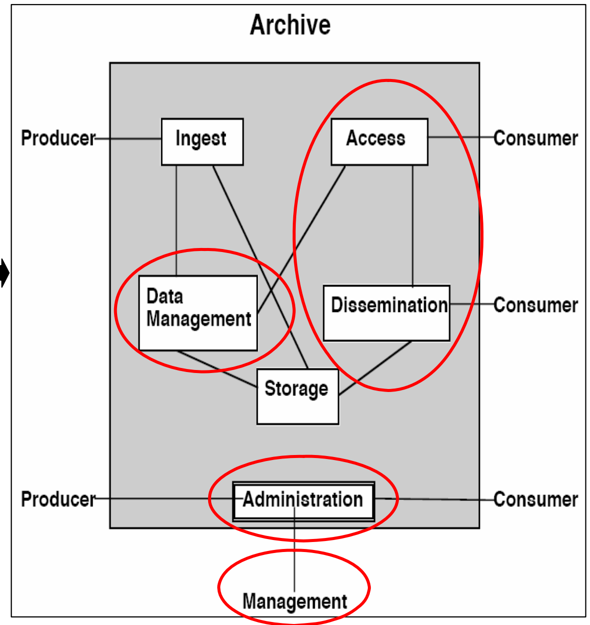
Version 3 (March 11, 1996) – No Figure Label

- Generic Services and Policy Makers Removed
- Access and Dissemination Grouped
- Metadata Management and Archival Management Separated

Figure 9 - Functional Model: Version 2 to Version 3 (Detailed View)



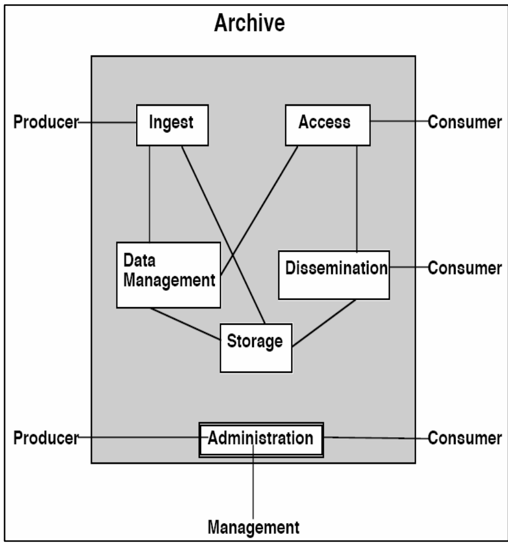
Version 3 (March 11, 1996) – No Figure Label



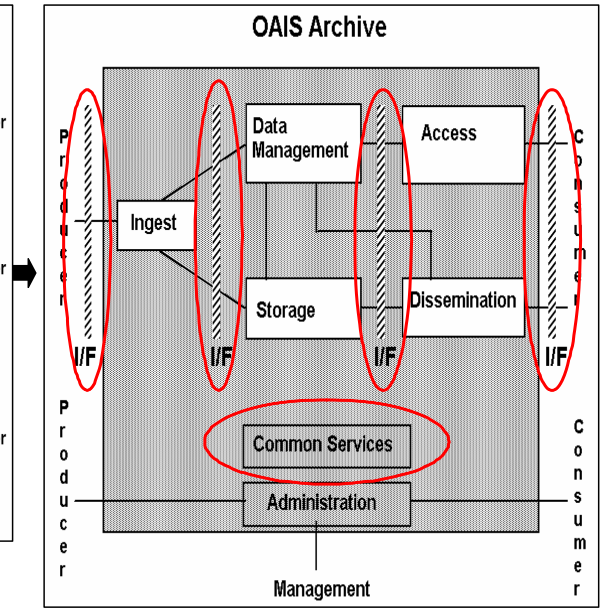
Version 4 (April 22, 1996) – Archive Functional Entities

- Management and Administration Added
- Product Management and Archival Management Combined as Data Management
- Access and Dissemination No Longer Grouped

Figure 10 - Functional Model: Version 3 to Version 4



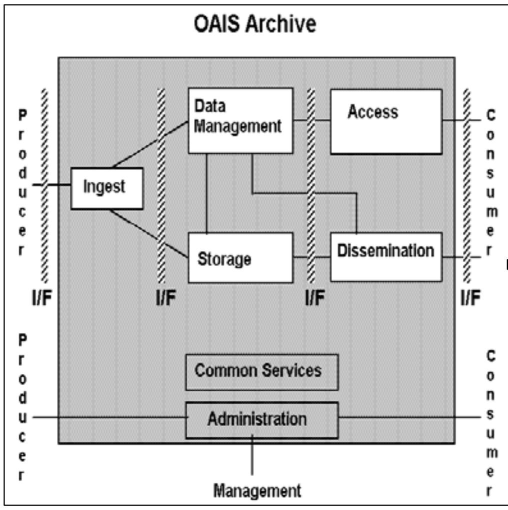
Version 4 (April 22, 1996) – Archive Functional Entities



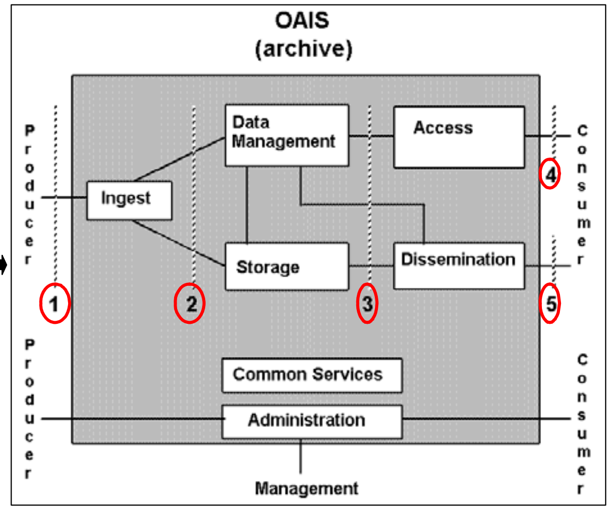
Version 6 (Sept 23, 1996) – OAIS Archive Functional Entities

- Common Services Reintroduced
- Vertical Bars Added to Indicate Boundaries Between Five "Views" (Producer, Ingest, Internal, Access and Dissemination)

Figure 11 - Functional Model: Version 4 to Version 6



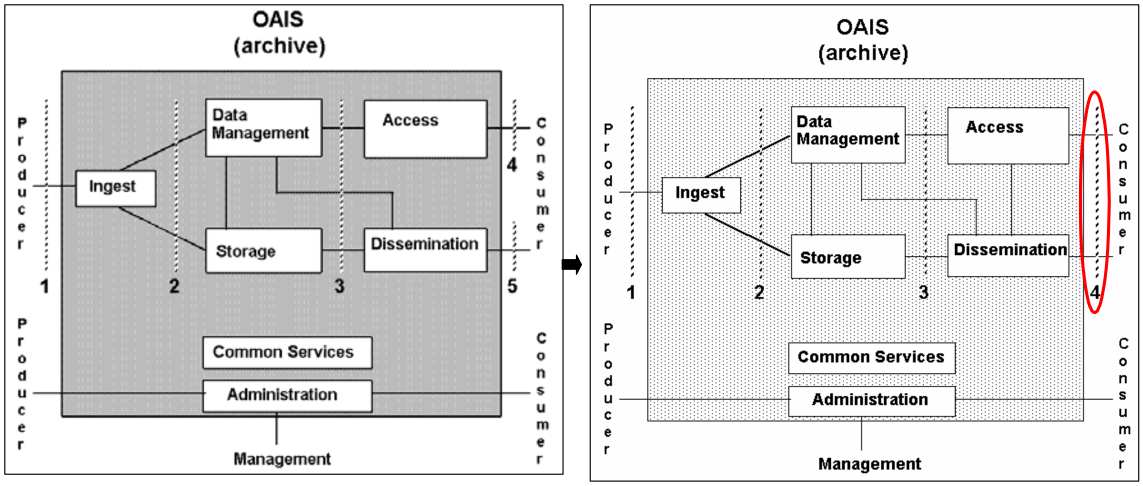
Version 6 (Sept 23, 1996) – OAIS Archive Functional Entities



Version 7 (Oct 25, 1996) - OAIS Functional Entities

- Numbered Labels Applied to Vertical Bars
- Separation of Vertical Bars Associated with Access and Dissemination

Figure 12 - Functional Model: Version 6 to Version 7

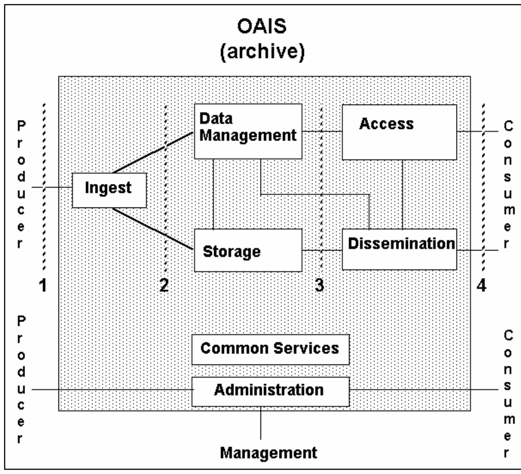


Version 7 (Oct 25, 1996) - OAIS Functional Entities

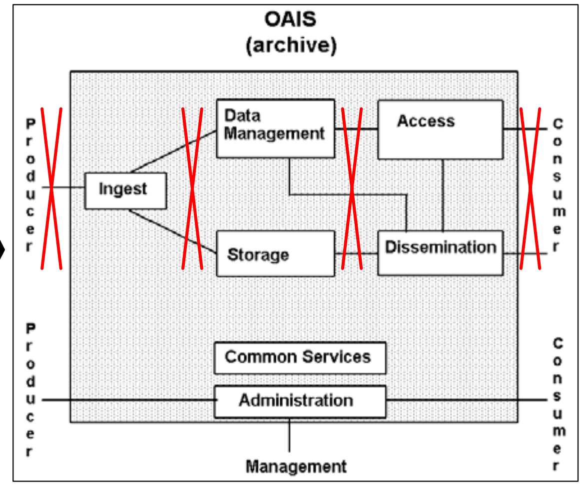
White Book 1 (April 10, 1997) – OAIS Functional Entities

- Vertical Bars 4 and 5 Re-merged

Figure 13 - Functional Model: Version 7 to White Book 1



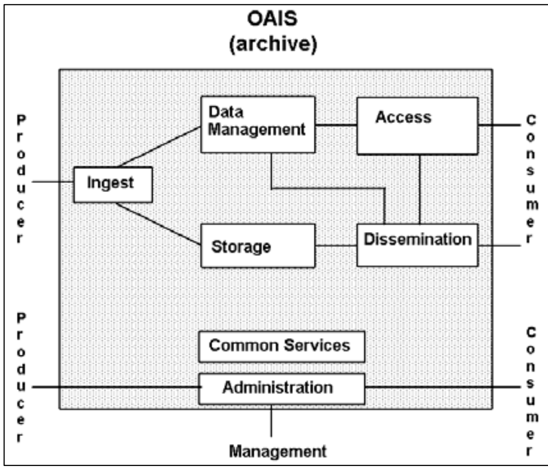
White Book 1 (April 10, 1997) – OAIS Functional Entities



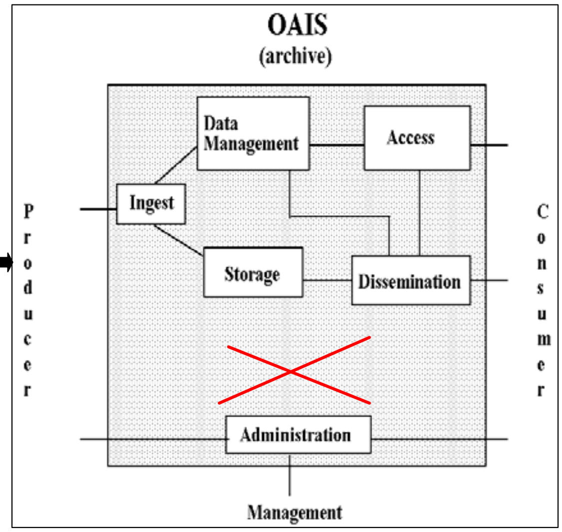
White Book 1.1 (July 5, 1997) – OAIS Functional Entities

- Vertical Bars Removed

Figure 14 - Functional Model: White Book 1 to White Book 1.1



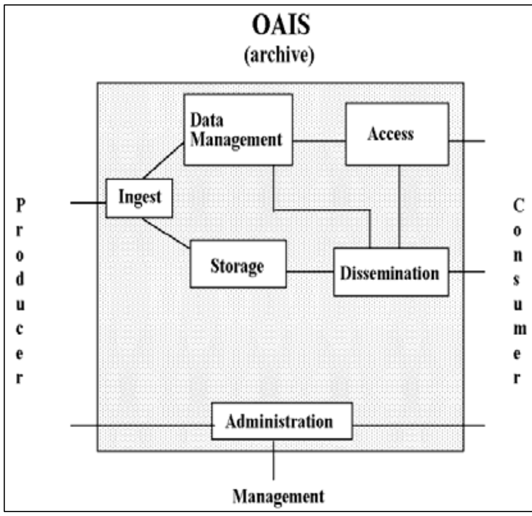
White Book 1.1 (July 5, 1997) – OAIS Functional Entities



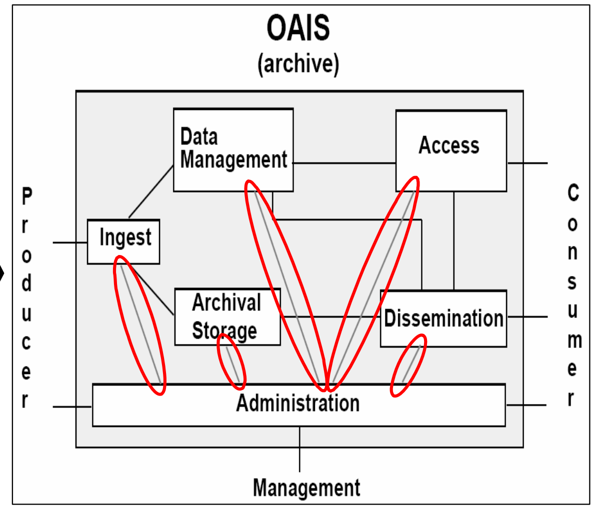
White Book 1.2 (Sept 29, 1997) – OAIS Functional Entities

- Common Services Removed Again

Figure 15 - Functional Model: White Book 1.1 to White Book 1.2



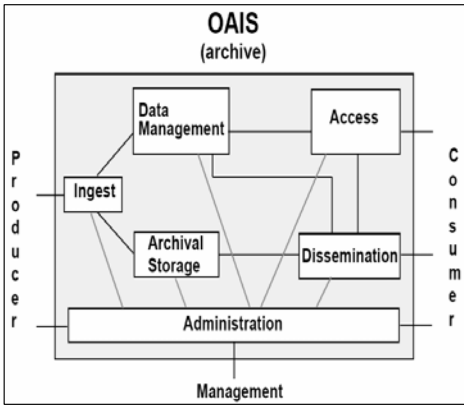
White Book 1.2 (Sept 29, 1997) – OAIS Functional Entities



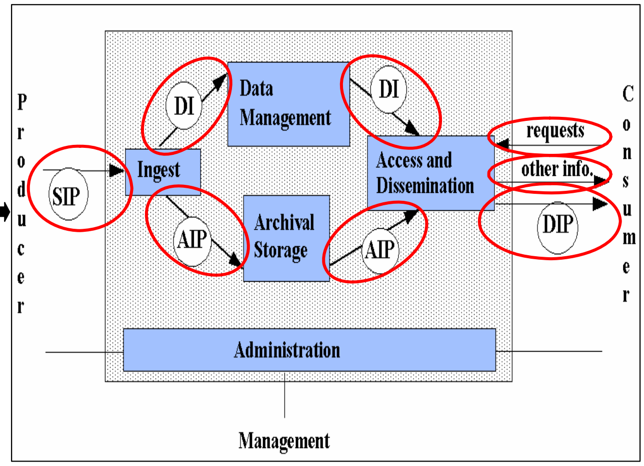
White Book 2 (Oct 15, 1997) – OAIS Functional Entities

- Internal Interfaces to Administration Represented
- Storage Changed to Archival Storage

Figure 16 - Functional Model: White Book 1.2 to White Book 2



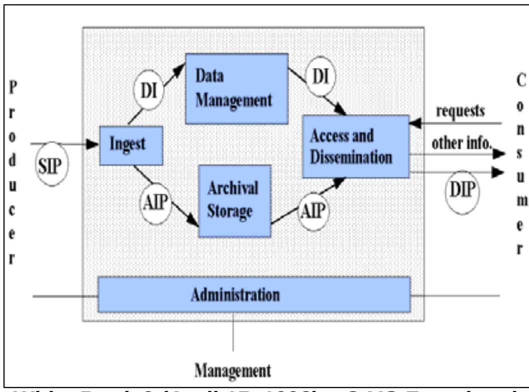
White Book 2 (Oct 15, 1997) – OAIS Functional Entities



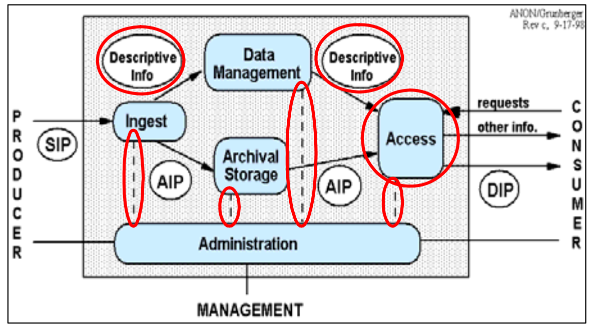
White Book 3 (April 15, 1998) – OAIS Functional Entities

- Access and Dissemination Combined
- Added Directionality to Lines between Entities
- Added “requests” and “other info.” between Consumer and Access and Dissemination
- Dropped Lines between Administration and other Internal Entities
- Added SIP, DI, AIP, DIP Circles

Figure 17 - Functional Model: White Book 2 to White Book 3



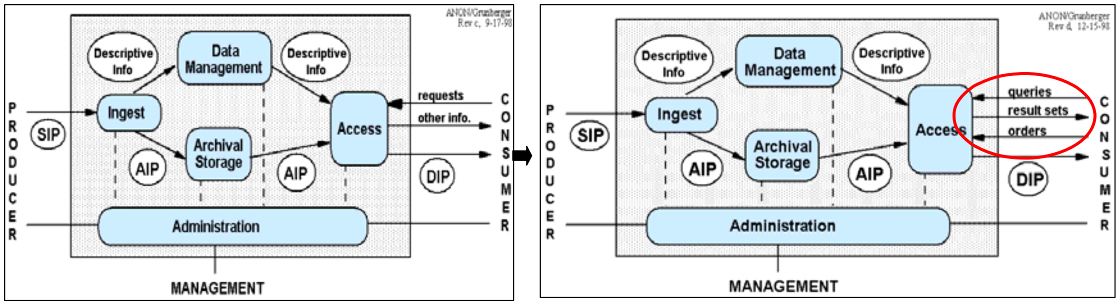
White Book 3 (April 15, 1998) – OAIS Functional Entities



White Book 4 (Sept 17, 1998) – OAIS Functional Entities

- DI Spelled out as Descriptive Info
- Lines to Administration Reintroduced
- Access and Dissemination Changed to Access

Figure 18 - Functional Model: White Book 3 to White Book 4

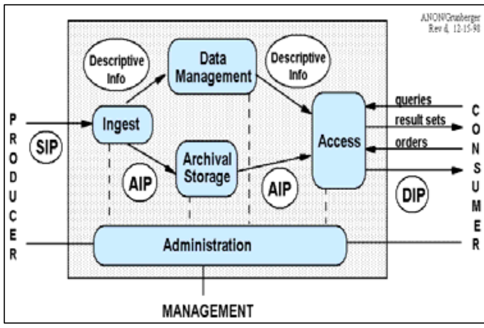


White Book 4 (Sept 17, 1998) – OAIS Functional Entities

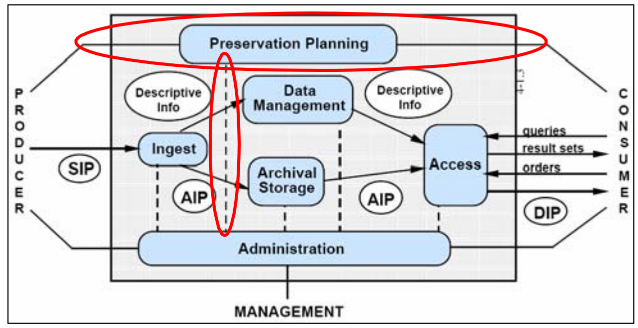
White Book 5 (April 21, 1999) – OAIS Functional Entities

- Lines between Access and Consumer Changed from "requests" and "other info" to "queries," "result sets," and "orders"

Figure 19 - Functional Model: White Book 4 to White Book 5



White Book 5 (April 21, 1999) – OAIS Functional Entities



Red Book 1.1 (April 2001) – OAIS Functional Entities

- Added Preservation Planning Entity
- Dashed Line Added to Connect Administration and Preservation Planning
- Added Lines to Connection Preservation Planning with Producer and Consumer
- No Changes to Functional Model after Red Book 1.1

Figure 20 - Functional Model: White Book 5 to Red Book 1.1

Appendix 8 – Timeline of Development Stages, Documents and Workshops

Date		Document	ISO Archiving Workshop	Stage
1994	April	Work item proposal (April 15)		Stage 1 – Preliminary Groundwork
	May			
	June			
	July			
	Aug			
	Sept			
	Oct			
	Nov			
	Dec			
1995	Jan			
	Feb			
	March			
	April			
	May			
	June			
	July			
	Aug			
	Sept	Version 1 (Sept 14)		
	Oct		1st US (Oct 11-12); 1st International (Oct 26-27)	Stage 2 - Early Meetings and Drafts
	Nov			
	Dec	Version 2 (Dec 19)	2nd US (Dec 19-20)	
1996	Jan			
	Feb			
	March	Version 3 (March 11)	3rd US (March 19-20); French (March 20-21)	
	April	Version 4 (April 22)	2nd International (April 29-30)	
	May			
	June			
	July	Version 5 (July 5)	4th US (July 10-11)	
	Aug			
	Sept	Version 6 (Sept 23)		
	Oct	Version 7 (Oct 25)	5th US (Oct 2-3)	
	Nov		3rd International (Nov 4-5)	
	Dec			
1997	Jan	Version 8 (Jan 6)	Sixth US (Jan 8)	
	Feb			
	March			
	April	White Book 1 (April 1)	7th US (April 16-17)	Stage 3 - Formalization & Wider Exposure
	May		4th International (May 12-14)	
	June			
	July	White Book 1.1 (July 5)	8th US (July 16-17)	
	Aug			
	Sept	White Book 1.2 (Sept 29)	UK (Sept 10); 9th US (Sept 30-Oct 1)	
	Oct	White Book 2 (Oct 15)	5th International (Oct 27-29)	
	Nov			
	Dec			
1998	Jan		10th US (Jan 28-30)	
	Feb			
	March			
	April	White Book 3 (April 15)	11th US (April 1-3)	
	May		6th International (May 13-16)	
	June		DADS (June 22-26)	
	July			

	Aug			
	Sept	White Book 4 (Sept 17)	13th US (Sept 16-18)	
	Oct		Seventh International (Oct 26-30)	
	Nov			
	Dec		Fourteenth US (Dec 16-17)	
1999	Jan			
	Feb			
	March			
	April	White Book 5 (April 21)		
	May	Red Book 1	8th International (May 11-13)	**Stage 4 - Becoming a CCSDS Recommendation**
	June		15th US (June 10-11)	
	July			
	Aug			
	Sept			
	Oct		AWIICS (Oct 13-15)	
	Nov		9th International (Nov 9-10)	
	Dec			
2000	Jan			
	Feb			
	March			
	April			
	May		10th International (May 12-15)	
	June			
	July		17th US (July 19-20)	
	Aug			
	Sept		18th US (Sept 14-15)	
	Oct			
	Nov		11th International (Nov 1-3)	
	Dec			
2001	Jan			
	Feb		19th US (Feb 20-23)	
	March			
	April	Red Book 1.1 (April 20)	20th US (April 10-11)	
	May		12th International (May 14-16)	
	June	Red Book 1.2; Red Book 2		
	July			
	Aug			
	Sept			
	Oct		Digital Curation (Oct 19); 13th International (Oct 22-24)	
	Nov			
	Dec			
2002	Jan	Blue Book		**Stage 5 - ISO Standardization**
	Feb			
	March			
	April			
	May			
	June			
	July			
	Aug			
	Sept			
	Oct			
	Nov			
	Dec			
2003	Jan			
	Feb	International Standard Published (Feb 24)		

Appendix 9 – Standards Development within CCSDS and ISO

Organizational actors that formally participate in the CCSDS fall into four categories: Member Agency, Observer Agency, Liaison, or Associate. In order to gain one of those four designations, an organizational actor must submit a written petition to the CCSDS Secretariat ("Procedures Manual for the Consultative Committee for Space Data Systems," 2002, p.3-5).[52]

Member Agencies are "governmental or quasi-governmental organizations" with "significant responsibilities for space development, operations, or research" who are willing and able to "participate substantially in CCSDS activities" (p.3-6). Only Member Agencies have voting rights. They name individual representatives to the CCSDS Management Council (CMC) and are expected to send members to all CCSDS technical working groups. When Member Agencies develop internal standards, they are expected to comply with CCSDS Recommendations. At the time that the CCSDS issued the OAIS as a final Recommendation (Blue Book), there were 10 Member Agencies.[53]

Observer Agencies "have a strong interest in space development, operations, or research" and "indicate a desire to participate in CCSDS activities but at a reduced level of effort" (p.3-6). They are "encouraged" but not required to ensure that their own internal standards comply with CCSDS Recommendations and to take part in

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[52] During the period when the Reference Model was developed, the CCSDS Procedures Manual underwent several rounds of revisions. For the purpose of this brief explanation, I have chosen to cite Issue 8, dated July 2002.

[53] The Member Agencies were, and still are, Agenzia Spaziale Italiana (ASI) – Italy; British National Space Centre (BNSC) - United Kingdom; Canadian Space Agency (CSA) – Canada; Centre National d'Etudes Spatiales (CNES) – France; Deutsches Zentrum für Luft- und Raumfahrt (DLR) – Germany; European Space Agency (ESA) – Europe; Instituto Nacional de Pesquisas Espaciais (INPE) – Brazil; National Aeronautics and Space Administration (NASA) – USA; National Space Development Agency of Japan (NASDA) – Japan (now Japan Aerospace Exploration Agency, JAXA); Russian Space Agency (RSA) - Russian Federation (now Roskosmos).

working groups. At the time that the CCSDS issued the OAIS as a Blue Book, there were 23 Observer Agencies.[54]

Liaison organizations are “governmental or private” actors that have “developmental programs in the areas of space-related data and information systems.” They can be “non-commercial, standards-developing organizations operating in areas similar to those of the CCSDS.” They receive copies of CCSDS documents and are “welcome to submit comments or initiate Review Item Dispositions (RIDs)” (p.3-6). Liaison organizations are usually involved with the CCSDS based on a particular area of interest, rather than to have a standing involvement in all CCSDS activities. There are currently 10 Liaison organizations to the CCSDS.[55]

Associates (now called Commercial Associates) are “scientific or industrial organizations” that are “sponsored by a Member or Observer Agency in their country.” They are able to “monitor closely CCSDS activities” by receiving copies of documents. At the discretion of their sponsoring Agencies, Associates can submit comments or RIDs and “participate in CCSDS technical meetings and discussion forums” (3-6, 3-7). There are currently 115 Commercial Associates to the CCSDS.

The CCSDS is a liaison organization to Technical Committee 20 (Aircraft and Space Vehicles), Subcommittee 13 (Space Data and Information Transfer Systems) of the ISO. The formal Secretariat for TC 20/SC 13 is the American National Standards

[54] There are now 22 Observer Agencies.

[55] American Institute for Aeronautics and Astronautics, Committee on Earth Observation Satellites (CEOS), Committee on Space Research (COSPAR), Interagency Operations Advisory Group (IOAG), International Society for Photogrammetry and Remote Sensing, ISO/IEC JTC 1 SC 2, U.S. National Archives and Records Administration (NARA), National Information Standards Organization (NISO), Norwegian Technology Standards Institution, and World Meteorological Organization.

Institute (ANSI), and it is administered by the U.S. National Aeronautic and Space Administration (NASA).

Once the Management Council (MC) has approved a New Work Item (NWI) and assigned it to a technical panel (in this case, Panel 2), the Concept Paper (CP) associated with the NWI "is discussed, analyzed, and fully developed during panel meetings. (In order to conserve panel resources, the panel chairperson may elect to assign the CP to a small group of appropriate technical experts for development)" ("Procedures Manual," 2002, p.5-2). Once the panel has reached consensus on the content of the CP, it becomes a White Book, which is a "preliminary draft of a planned CCSDS Recommendation or Report" and is "not necessarily endorsed by any CCSDS Member or Observer Agency or given any CCSDS-external distribution." ("Procedures Manual," 2002, p.1-3).[56] When the panel reaches consensus on the White Book, the chair of the panel then petitions the MC to release the document as a Red Book, which "describes the technical consensus within a panel and may incorporate unofficial Agency comments received at the 'working level.'" By assigning Red Book status to version of a proposed Recommendation, the MC is indicating that it "believes that the document is technically mature and ready for extensive and formal review by appropriate technical organizations within each Member Agency. Official Member Agency comments about (or approval of) the RB are sought" (p.1-3, 1-4).

The Red Book then undergoes a period of Member Agency review, which can involve review and comment on more than one successive versions of the Red Book

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[56] Version 8 (2002) of the "Procedures Manual" also indicates that White Books are "not necessarily endorsed by any CCSDS Member or Observer Agency or given any CCSDS-external distribution." In the case of the Reference Model, copies of the White Books were widely distributed outside of the CCSDS, and they were cited in external literature as early as White Book 3.

(subsequent Red Book releases do not require additional MC approval). Member Agencies indicate whether or not they approve the document, Observer Agencies can indicate whether or not they "concur," and both types of agencies can submit comments using a Review Item Disposition (RID) initiation form. When Associate members wish to submit comments, they should "forward them to their respective sponsoring Agency for review and disposition by that Agency" (p.5-6).

After receiving RIDs, the Technical Editor (in this case, Don Sawyer) is responsible for scheduling "editing meetings" for the "sole purpose" of developing responses to comments - called dispositions for the Review Items (RIs). The Technical Editor should ensure that "all written comments are discussed and written dispositions provided to the submitter," except that "minor or editorial" suggestions can be incorporated into the Red Book without providing a written response (p.5-6).

Once there is Member Agency consensus on a Red Book, the panel chair petitions the MC to release and distribute it as a CCSDS Recommendation (Blue Book). If it approves this petition, the MC issues a resolution authorizing the Secretariat to distribute the document as a Blue Book, which

> represents the consensus of the appropriate implementing organizations within each Member Agency. Member Agency approval of a Blue Book implies an intent to reflect its provisions in future data systems standards developed through internal mechanisms (p.1-4).

The CCSDS procedures are designed in order to allow its Recommendations to become ISO Standards, and the steps in the CCSDS process map directly to steps in the ISO process. Within the ISO, standards development is carried out through Technical Committees (TC) and Subcommittees (SC). In order for a new CCSDS effort to be part of the ISO process, a New Work Item Proposal is submitted to the Secretariat of SC 13, and it is then circulated to SC 13 members for voting. The voting SC 13 members indicate whether or not they support the addition of the NWI to the work of SC 13 and whether or not they are "prepared to participate in the development of the project." A CCSDS White Book is considered an ISO Working Draft, which does not require any special ISO endorsements. During the CCSDS Red Book phase, the document is considered an ISO Committee Draft, and it is circulated to all members of SC 13. This is "the principal stage at which comments from national bodies are taken into consideration, with a view to reaching consensus on the technical content" (*ISO/IEC Directives, Part 1*, 1997, p.22). When asked to do so by CCSDS Panel 2, the SC 13 members vote on whether or not they agree to the circulation of the document as a Draft International Standard (DIS). If circulation is approved by the SC 13 members, then the document goes out for review as a DIS to all ISO national member bodies. Member bodies can submit a positive, negative or abstention vote, and they can offer comments associated with the vote. The SC 13 Secretariat reports on the results of the vote and attempts to resolve negative votes. This DIS review and vote process can potentially go through more than one iteration. Upon the decision of the SC 13 chair, the content of the document (now a CCSDS Blue Book) is considered fixed. The document is circulated again to all ISO national member bodies, now as a Final Draft International Standard. This is a more direct yes/no vote than with the previous DIS, and "editorial or technical amendments are not acceptable at this stage" (p.26). Affirmative votes cannot include comments, nor can they be contingent on making modifications to the document. Negative votes can include reasons, but do not need to be addressed. Instead, the reasons are submitted to SC 13 "for consideration at the time of the next review of the

International Standard" (p.26).[57] If a two-third majority votes in favor of the Blue Book (FDIS), the CEO of the ISO corrects any final error reported by SC 13 and then publishes the document as an International Standard.

[57] Both the ISO and CCSDS require periodic reviews of existing Recommendations/International Standards every five years. The OAIS Reference Model will be subject to review in 2007, at which time the comments associated with negative votes on the Blue Book will be taken into consideration.

Appendix 10 – ISO Archiving Workshop Participation Data

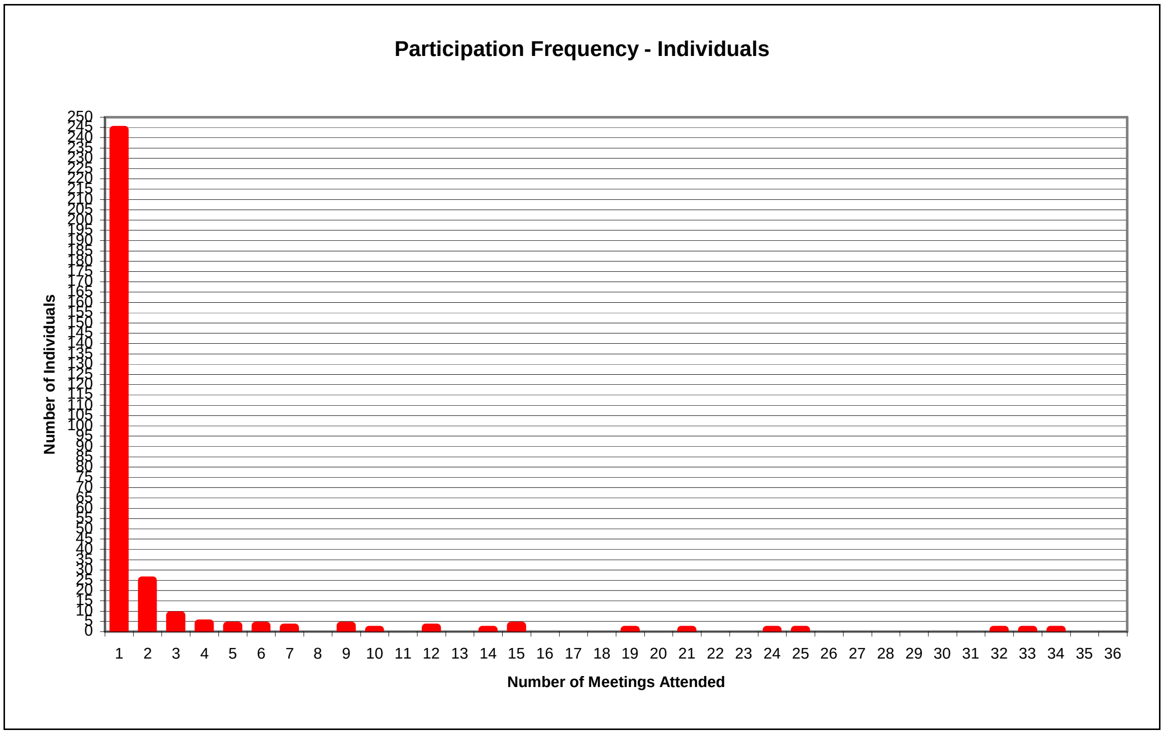

Figure 21 - Participation Frequency - Individuals

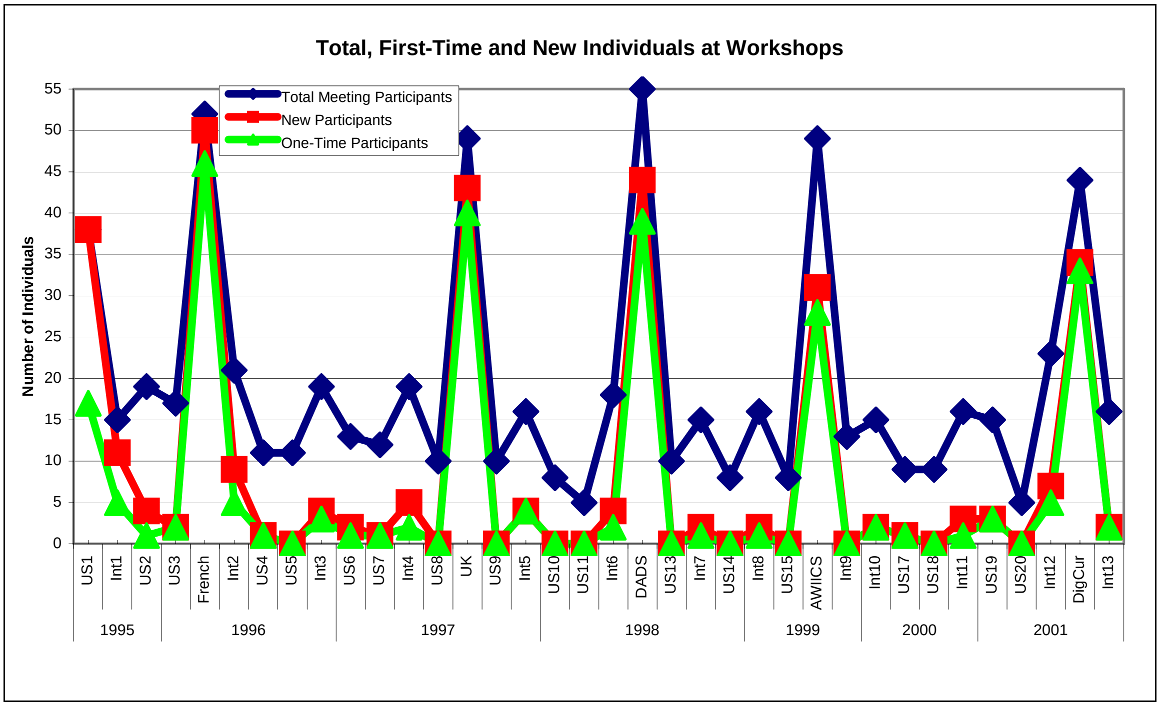

Figure 22 - Total, First-Time and New Individuals at Workshops

Table 1 - Active Individual Participants - Based on Workshops Attended

Eleven names (with bold text and asterisks in the table), which are on the list of most active participants overall, and for each of the three stages (bold OA affiliation indicates the OA is also one of the five top OA participants):

- Donald Sawyer (**GSFC**, NASA)
- Lou Reich (**CSC**, **GSFC**, NASA)
- John Garrett (**GSFC**, NASA, Hughes STX, Raytheon STX, Raytheon ITSS)
- Bruce Ambacher (**CER**, NARA)
- Alan Wood (NASA, Hughes STX, Lockheed-Martin, Ames LSDA, LSDA, Life Sciences Division)
- Mike Martin (**JPL**)
- Robert Stephens (NASA, **CSC**, SGT, QSS Group)
- David Giaretta (BNSC, RAL)
- Patrick Mazal (**CNES**)
- Claude Huc (**CNES**)
- Elizabeth Brinker (**GSFC**, NASA)

Overall (36 Total Workshops)		**Stage 2 (10 Total Workshops)**		**Stage 3 (13 Total Workshops)**		**Stage 4 (13 Total Workshops)**	
Name	Workshops	Name	Workshops	Name	Workshops	Name	Workshops
***Sawyer**	34	***Garrett**	9	***Garrett**	12	***Sawyer**	13
***Reich**	33	***Reich**	9	***Reich**	12	***Reich**	12
***Garrett**	32	***Sawyer**	9	***Sawyer**	12	***Wood**	12
***Ambacher**	25	***Martin**	7	***Ambacher**	9	***Ambacher**	11
***Wood**	24	Blaese	7	***Stephens**	9	***Garrett**	11
***Martin**	21	Grunberger	6	***Wood**	9	***Giaretta**	7
***Stephens**	19	Davis	6	***Martin**	8	***Huc**	6
***Giaretta**	15	***Ambacher**	5	Grunberger	7	***Martin**	6
Grunberger	15	***Stephens**	5	***Giaretta**	5	***Mazal**	6
***Mazal**	15	Voels	5	***Mazal**	5	Lucas	6
***Huc**	14	***Mazal**	4	Minguillon	5	Peccia	6
Minguillon	12	***Huc**	4	***Huc**	4	Dale	5
Peccia	12	Cryder	4	Peccia	4	Minguillon	5
***Brinker**	10	Rainey	4	Pinna	4	Pinna	5
Blaese	9	***Brinker**	3	Brinker	3	***Stephens**	5
Davis	9	Cudlip	3	Davis	3	Beagrie	4
Pinna	9	Drexler	3	Inoue	3	***Brinker**	4
Inoue	7	***Giaretta**	3			Inoue	4
Voels	7	Kempster	3			Kobler	3
Cudlip	6	Thieman	3				
Kobler	6	Williams	3				
Lucas	6	***Wood**	3				
Beagrie	5						
Dale	5						
Williams	5						

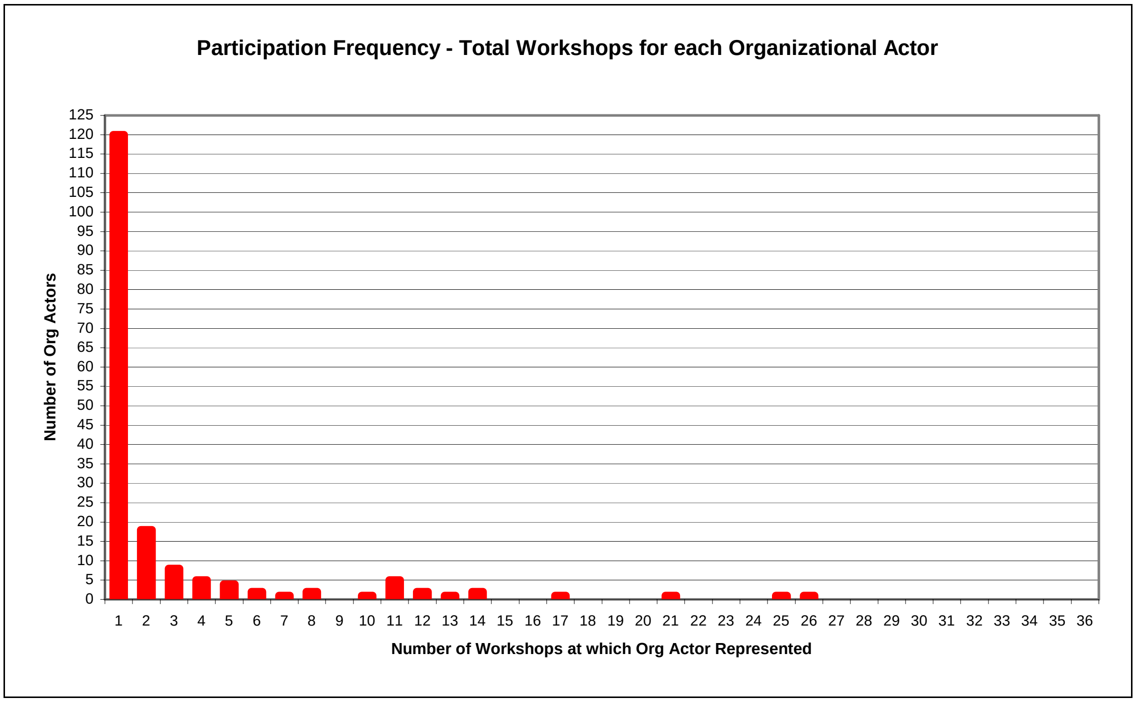

Figure 23 - Participation Frequency - Total Workshops for each Organizational Actor

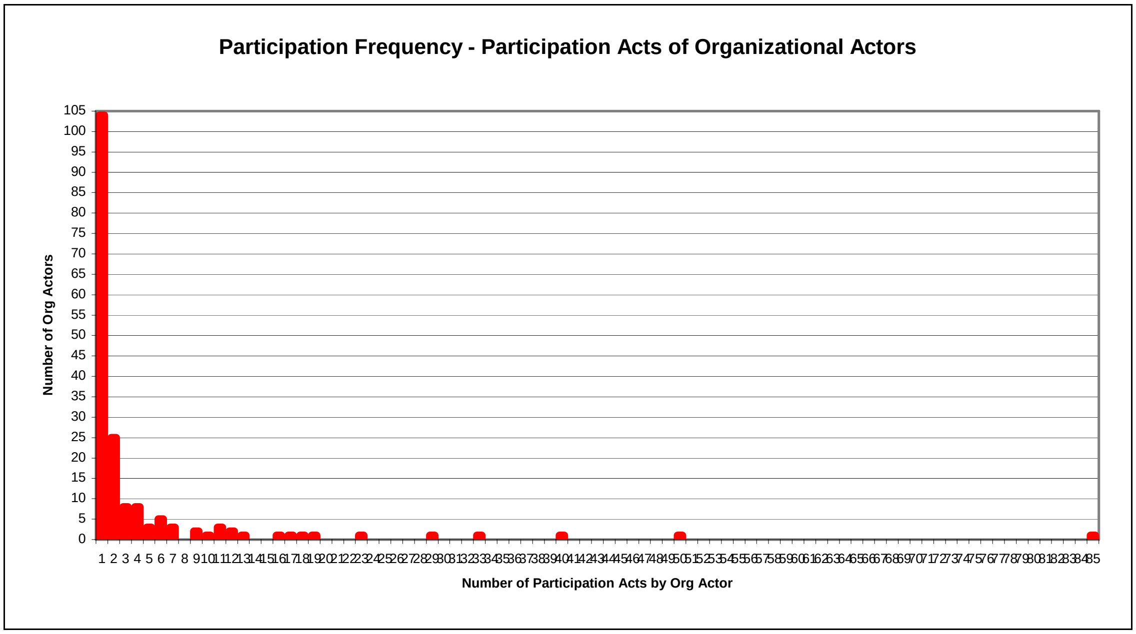

Figure 24 - Participation Frequency - Participation Acts of Organizational Actors

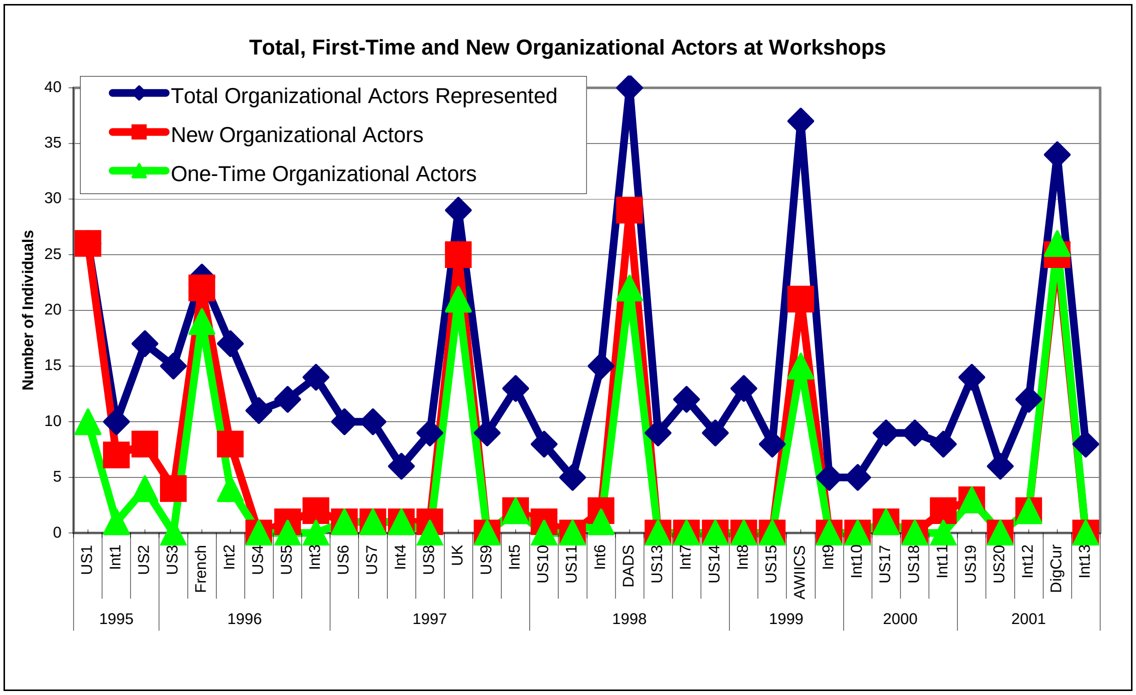

Figure 25 - Total, First-Time and New Organizational Actors at Workshops

Table 2 - Active Organizational Actors - Number of Workshops[58]

Five names with asterisks and bold text are on the list of most active participants overall, and for each of the three stages: CSC, GSFC, JPL, CER, and CNES

Overall (36 Total Workshops)		**Stage 2 (10 Total Workshops)**		**Stage 3 (13 Total Workshops)**		**Stage 4 (13 Total Workshops)**	
Name	Number of Workshops	Name	Number of Workshops	Name	Number of Workshops	Name	Number of Workshops
***CSC**	26	***CSC**	9	***CSC**	11	BNSC	7
***GSFC**	25	***GSFC**	9	***GSFC**	9	***GSFC**	7
***JPL**	21	Hughes STX	8	***CER**	8	Lockheed	7
***CER**	17	***JPL**	7	***JPL**	8	***CNES**	6
***CNES**	15	LSDA	7	Ames LSDA	7	***CSC**	6
BNSC	14	APL	5	Raytheon STX	7	ESA	6
APL	13	***CER**	4	APL	6	***JPL**	6
Hughes STX	12	***CNES**	4	SGT	6	NARA	6
Raytheon STX	12	LASP	4	BNSC	5	NASA	6
Ames LSDA	11	NWAD	4	***CNES**	5	***CER**	5
ESA	11	Teledyne Brown Engineering	4	ESA	4	Raytheon STX	5
Lockheed-Martin	11	BMDO	3	Hughes STX	4	RLG	5
NASA	11	DERA Farnborough	3	Lockheed-Martin	4	Ames LSDA	4
SGT	11	GSOC	3	NASA	4	NASDA	4
LSDA	10	RAL	3	ESOC	3	OCLC	4
NARA	8	U.S. Army	3	LASP	3	SGT	4
NASDA	8			Logica	3	JISC	3
LASP	7			NASDA	3	CEDARS	3
RLG	6			RAL	3		
RAL	6						

[58] For full organizational actor names, see List of Acronyms (p.xix).

Table 3 - Active Organizational Actors - Number of Participation Acts[59]

Five names with asterisks and bold text are on the list of most active participants overall, and for each of the three stages: GSFC, CNES, CSC, JPL and CER

Overall (36 Total Workshops)		**Stage 2 (10 Total Workshops)**		**Stage 3 (13 Total Workshops)**		**Stage 4 (13 Total Workshops)**	
Name	Part. Acts	Name	Part. Acts	Name	Part. Acts	Name	Part. Acts
***GSFC**	85	***GSFC**	38	***GSFC**	27	***CNES**	29
***CNES**	70	***CNES**	27	***CNES**	14	NASA	25
NASA	40	Hughes STX	21	***CSC**	14	***GSFC**	20
***CSC**	33	***CSC**	13	NASA	13	BNSC	10
Hughes STX	29	LSDA	8	Raytheon STX	11	ESA	10
***JPL**	23	***JPL**	7	***JPL**	9	NARA	8
BNSC	19	RAL	6	***CER**	8	***JPL**	7
***CER**	18	APL	5	Hughes STX	8	Lockheed	7
ESA	17	GSOC	5	Logica	8	***CER**	6
Raytheon STX	16	Teledyne	5	Ames LSDA	7	***CSC**	6
APL	13	***CER**	4	BNSC	7	JISC	6
Lockheed	12	LASP	4	DERA	7	CEDARS	5
RAL	12	DERA Farnborough	4	APL	6	Raytheon SXT	5
Ames LSDA	11	NWAD	4	ESA	6	RLG	5
LSDA	11	BMDO	4	RAL	6	Ames LSDA	4
SGT	11	U.S. Army	4	SGT	6	NASDA	4
NARA	10	EDF	4	Lockheed	5	OCLC	4
Logica	9					SGT	4
NASDA	9						

[59] Number of participation acts = number of workshops at which organizational actor was represented multiplied by the number of individuals from the organization actor at each of those workshops.

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