Technology Responsiveness for Digital Preservation: A Model

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Abstract

Digital preservation may be defined as the cumulative actions undertaken by an organisation or individual to ensure that digital content is usable across generations of information technology. As technological change occurs, the digital preservation community must detect relevant technology developments, determine their implications for preserving digital content, and develop timely and appropriate responses to take full advantage of progress and minimize obsolescence.

This thesis discusses the results of an investigation of technology responsiveness for digital preservation. The research produced a technology response model that defines the roles, functions, and content component for technology responsiveness. The model built on the results of an exploration of the nature and meaning of technological change and an evaluation of existing technology responses that might be adapted for digital preservation. The development of the model followed the six-step process defined by constructive research methodology, an approach that is most commonly used in information technology research and that is extensible to digital preservation research.

This thesis defines the term *technology responsiveness* as the ability to develop continually effective responses to ongoing technological change through iterative monitoring, assessment, and response using the technology response model for digital preservation.

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Declaration

I, Nancy Yvonne McGovern, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm this has been indicated in the thesis.

Signature: ____

Date: __________________

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List of abbreviations

4S	Society for Social Studies of Science
ACM	Association for Computing Machinery
AHDS	Arts and Humanities Data Service [United Kingdom]
AHRQ	Agency for Healthcare Research and Quality [United States]
AIC	Archival Information Collection [source: OAIS]
AIP	Archival Information Package [source: OAIS]
AIP	American Institute for Physics
AJETS	Australian Journal of Emerging Technologies and Society
ALA	American Library Association
AONS	Automated Obsolescence Notification System [National Library of Australia]
API	Application Programming Interface
ARPANET	Advanced Research Projects Agency Network [United States]
AUTM	Association of University Technology Managers [United States]
AWIICS	Archival Workshop on Ingest, Identification, and Certification Standards
Beta	Betamax videocassette tape made by Sony Corporation
BIS	Bureau of Industry and Security, United States Department of Commerce
CaMiLEON	Creative Archiving at Michigan & Leeds: Emulating the Old on the New
CART	Committee on Automated Records and Techniques, Society of American Archivists
CCSDS	Consultative Committee for Space Data Systems
CD-ROM	Compact Disc Read-Only Memory
CDL	California Digital Library
Cedars	Curl Exemplars in Digital Archives [United Kingdom]

CHIN	Canadian Heritage Information Network
CLIR	Council on Library and Information Resources
CRL	Center for Research Libraries
DC	District of Columbia
DCC	Digital Curation Centre [United Kingdom]
DEC	Digital Equipment Corporation [DEC Professional computer]
DELOS	Network of Excellence on Digital Libraries
DigCCurr	Digital Curation Curriculum projected at the University of North Carolina at Chapel Hill
DIKW	Data, Information, Knowledge, Wisdom
D-Lib	Digital Libraries [Magazine]
DoD	United States Department of Defense
DigiCULT	Digital Culture Forum [Europe]
DIA	Detroit Institute of Arts
DIP	Dissemination Information Package [source: OAIS]
DNS	Domain Name Server
DP	Digital Preservation
DPC	Digital Preservation Coalition [United Kingdom]
DPE	DigitalPreservationEurope
DRAMBORA	Digital Repository Audit Method Based on Risk Assessment
DTI	Department of Trade and Industry [United Kingdom]
DVD	Digital Versatile Disc or Digital Video Disc
EPA	Environmental Protection Agency [United States]
EPTA	European Parliamentary Technology Assessment
ETTC	Engineering Technology Transfer Center, University of Southern California
EU	European Union

FCLA	Florida Center of Library Automation
FLC	Federal Laboratory Consortium [United States]
FLUIDS	Future Lines of User Interface Decision Support
FY	Fiscal Year
GAO	Government Accounting Office
GiMoDig	Geospatial Info-Mobility service by real-time Data-Integration and Generalisation
HD	High Definition
HSTAT	Heath Services Technology Assessment Texts, National Library of Medicine [United States]
HTA	Health Technology Assessment, National Health Service [United Kingdom]
HTAI	Health Technology Assessment International
HTML	HyperText Markup Language
IAIA	International Association for Impact Assessment
IASSIST	International Association for Social Science Information Service and Technology
ICA	International Council on Archives
ICPSR	Inter-university Consortium for Political and Social Research
ICT	Information Communications Technology
ICTA	International Center for Technology Assessment
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IJHTI	International Journal of Technology and Human Interaction
InterPARES	International Research on Permanent Authentic Records in Electronic Systems
iPres	International Conference on the Preservation of Digital Objects
ISO	International Organization for Standardization

IS&T	Society for Imaging Science and Technology
IT	Information Technology
JCDL	Joint Conference on Digital Libraries
JISC	Joint Information Systems Committee [United Kingdom]
JTC	Joint Technical Committee
kopal	Kooperativer Aufbau eines Langzeitarchivs digitaler Informationen or Co-operative Development of a Long-Term Digital Information Archive
KoLibRI	kopal Library for Retrieval and Ingest
LIFE	Life Cycle Information for E-Literature Project [United Kingdom]
LITA	Library and Information Technology Association.
LOCKSS	Lots of Copies Keeps Stuff Safe
METS	Metadata Encoding and Transmission Standard, Library of Congress [United States]
MIT	Massachusetts Institute of Technology
MSI	MSI, School of Mathematics and Systems Engineering, Växjo University, Sweden
NARA	National Archives and Records Administration [United States]
M&S	Modeling and Simulation
NASA	National Aeronautics and Space Agency
NDI	Non-Developmental Item
NDIIPP	National Digital Information Infrastructure Preservation Program, Library of Congress [United States]
nestor	Network of Expertise in long-term STOrage and availability of digital Resources in Germany
NHS	National Health Service [United Kingdom]
NIH	National Institutes of Health [United States]
NSF	National Science Foundation [United States]
NTTC	National Technology Transfer Center

OCLC	Online Computer Library Consortium
OED	Oxford English Dictionary
OECD	Organisation for Economic Co-operation and Development
O-O	Object-oriented technology
OAIS	Open Archival Information System
ONR	Office of Naval Research [United States]
OSC	Ohio Supercomputer Center
OTA	Office of Technology Assessment [United States]
PADI	Preserving Access to Digital Information [Australia]
PAIMAS	Producer-Archive Interface – Methodology Abstract Standard [source: OAIS]
PANIC	Preservation webservices Architecture for Newmedia and Interactive Collections
PARS	Preservation and Reformatting Section, American Library Association
PDI	Preservation Description Information
PLANETS	Preservation and Long-term Access through Networked Services [Europe]
PLEDGE	PoLicy Enforcement in Data Grid Environments [USA]
POST	Parliamentary Office of Science and Technology [United Kingdom]
PREST	Policy Research in Engineering, Science and Technology, University of Manchester
PRONOM	Online registry of information about file formats, United Kingdom National Archives
QinetiQ	as in kinetic [British defence technology company]
RAC	Digital Repository Audit and Certification
RLG	Research Libraries Group
SAA	Society of American Archivists
SGML	Standard Generalised Markup Language

SIP	Submission Information Package [source: OAIS]
SME	Small and Medium Enterprises
SPRU	Science and Technology Policy Research, University of Sussex
SRB	Storage Resource Broker, San Diego Supercomputer Center
STTT	International Journal on Software Tools for Technology Transfer
ST&HV	Science, Technology & Human Values [Journal]
SunSITE	Sun [Microsystems] Software, Information and Technology Exchange
TASC	Technology Assessment that considers the Social Consequences, University of Wollongong, Australia
TCP/IP	Transmission Control Protocol/Internet Protocol
TC20/SC13	Space data and information transfer systems technical committee of ISO
TDR	Trusted Digital Repository
TF	Technology Forecasting
TIFAC	Technology Information, Forecasting & Assessment Council [India]
TIFF	Tagged Image File Format
TRA	Technology Readiness Assessment, United States Department of Defense
TRAC	Trustworthy Repositories Audit & Certification
TRIZ	Theory of Inventive Problem Solving Journal
TW	Technology Watch
UIUC	University of Illinois at Urbana-Champagne
UK	United Kingdom
UKOLN	United Kingdom Office for Library and Information Networking
UML	Unified Modeling Language
UNC	University of North Carolina
UNESCO	United Nations Educational, Scientific and Cultural Organization

URL	Uniform Resource Locator
URN	Uniform Resource Name
USA	United States of America
USC	University of Southern California
USDA	United States Department of Agriculture
USGCRP	United States Global Change Research Program
UVC	Universal Virtual Computer
VATAP	Veterans Affairs Technology Assessment Program [United States]
VHS	Video Home System
VINE	Journal of Information and Knowledge Management Systems
WWW	World Wide Web
Xena	XML Electronic Normalising for Archives, National Archives of Australia
XML	Extensible Markup Language

Chapter 1. Introduction

1.1 Research Problem

> There is growing realisation that … future access to digital resources [is] threatened by technology obsolescence and to a lesser degree by the fragility of digital media. The rate of change in computing technologies is such that information can be rendered inaccessible within a decade. Preservation is therefore a more immediate issue for digital than for traditional resources. Digital resources will not survive or remain accessible by accident: pro-active preservation is needed.[1]

This quotation illustrates both the critical threat to digital preservation of changing technology and the acknowledgement of the problem within the digital preservation community. A challenge to addressing this threat is that the scope of the terms *technology obsolescence* and *technological change* have not been adequately defined. There has been virtually no discussion of and, therefore, little agreement on what responding to technological change might entail. No means to evaluate whether that objective has been achieved is currently available to the community. In practice, the notion of technology responsiveness has become conflated with the problem of technology obsolescence, which typically has been defined as the need to avoid file format obsolescence. Defined by these parameters, the starting point for approaches to dealing with the very serious challenges that ever-changing computing technologies present has been existing technology upon which current digital content, that is being preserved, relies. Indeed there has been little critical analysis of the potential scope of interest in information technology developments or the potential range of responses to technological change for digital preservation, beyond efforts devoted to avoiding file format obsolescence.

The singular goal of avoiding file format obsolescence is a reactive rather than a properly responsive approach to technological change. For over a decade, technology responsiveness within the digital preservation community has been narrowly focused on this goal. The community is now on the verge of establishing

[1] Joint Information Systems Committee (JISC), 'Digital Preservation: Continued Access to Authentic Digital Assets', briefing paper, November 2006, http://www.jisc.ac.uk/media/documents/publications/digitalpreservationbp_rtf.rtf (accessed 15 April 2008).

the means to detect obsolescence risks pertaining to file formats and is close to implementing the means to respond automatically to those risks.

There are many reasons to broaden this goal. For one, the development pattern for more complex combinations of technologies that may create, manage, or provide access to digital content are not addressed by efforts to prevent file format obsolescence. Relative to information systems and other complex combinations of technologies, file formats are a simple form of technology. Although time and effort is required for standards to emerge for new formats, file formats are described here as simple because a file format is often one component of more complex forms of digital content and becoming familiar with file formats is an increasingly known process within the digital preservation community. Even more important, a limited approach to technology responsiveness will not inform the digital preservation community about how to invest its resources, how to anticipate changes in technology, how to assess the relevance of the myriad changes in technology that might threaten a digital archive, how to prioritise and adjust the scope of interest on an on-going basis, or how to collaborate with other communities so that the responsibility of monitoring changing technology is shared. Nor does it take into account the full range of technology developments or potential implications of technological change. The solution to the problem of technological change must be broad enough to meet the objective fully. If the goal of technology responsiveness is only defined narrowly as avoiding obsolescence, no more than that will ever be achieved and there will be little chance to reap the potential benefits of adopting new technologies for digital preservation.

This thesis explores the opportunities and challenges of defining the scope of technology obsolescence for digital preservation beyond its immediate focus on the need to ensure the ability to read and use file formats and of broadening the scope of technology response beyond the specific goal of avoiding obsolescence. The investigation responds to the need within the digital preservation community for a formal definition of technology responsiveness and an approach for systematically and comprehensively tracking, evaluating, and responding to technological change. The research discussed in this thesis assessed and refined the scope of interest in technology developments for digital preservation, defined possible responses to technology for digital preservation that anticipate the implications of new technologies, and proposed a comprehensive approach to technology responsiveness by and for the digital preservation community.

The remainder of Chapter 1 provides background information for the discussion of the investigation of technology responsiveness for digital preservation. Section 1.2 details the research questions. Section 1.3 provides an overview of the digital preservation terminology and concepts that reflect prevailing practice and that are used implicitly and explicitly throughout the thesis. Section 1.4 traces the emergence of the digital preservation community for which the technology response model was developed (see Chapter 4) and considers the context of the digital preservation community in relation to wider communities. Section 1.5 documents the efforts to date within the digital preservation community to respond to technological change as a starting point for this research and as a means to identify gaps this research uncovered. Section 1.6 discusses the results of the literature review that was conducted for the research. Section 1.7 introduces the model and the technology response example to demonstrate the application of the model by defining the starting points for each. Section 1.8 defines the research methodology that this research identified and developed for this research. Section 1.9 discusses the limitations of the research. Section 1.10 outlines the organisation of the thesis. The chapter considers the results and contributions of the research.

1.2 Research Questions

The research questions are built upon two assertions, which are discussed in Sections 1.4 and 1.5: 1) the digital preservation community is emerging and can be documented, observed, and served; and 2) the digital preservation community has not yet investigated and addressed comprehensively and systematically the ongoing technological change with which it needs to cope. Informed by these observations, the following four research questions framed the technology responsiveness investigation.

How would developing an understanding of the nature and cycle of technology developments contribute to the definition of a scope of interest in technological change that is appropriate to digital preservation objectives? Although the challenge of information technology evolution has been formally acknowledged by the digital preservation community, the community has not identified a means to systematically define, apply, and test its scope of concern regarding information technology developments. The absence of a measurable scope of concern limits the ability of the digital preservation community to continually and comprehensively monitor relevant information technology developments. Identifying a means to determine and adjust the scope of interest in technology developments for digital preservation is the objective for this research question.

How have communities responded to technological change and to what extent are existing models and examples of technology responses effective for digital preservation? The results of the review of current approaches to technology monitoring and response that have emerged within the digital preservation community demonstrated that most approaches limit the scope of concern to monitoring existing file formats to avoid file format obsolescence. The motivations for and outcomes of technology responses by other communities might produce useful new contributions for enabling technology responsiveness for digital preservation. This research question considered the potential to expand the capability of the digital preservation community to respond to technological change.

What approach could be devised for use by the digital preservation community to continually detect, evaluate, and respond to technology developments that have potential implications for the long-term preservation of digital content? The investigation addressed two components of technology responsiveness: the means to track purposefully and respond effectively to technological change. This research question begins with the combination of the results from addressing the first two research questions. The intended outcome is a proposed model to provide the means for technology responsiveness for digital preservation.

How might the potential implications of the emergence of a technology development be determined and evaluated to develop responses that are appropriate to the technology development? The technology response model for digital preservation is demonstrated using a technology example, namely object-based systems. The example uses the findings from the first three research questions to show how the digital preservation community might detect, monitor, assess, and respond to a given technology development.

These four core research questions framed the investigation of technology responsiveness for digital preservation that this thesis discusses. The concluding discussion in the thesis considers the adequacy of the responses to the questions provided by the research and presented in this thesis.

1.3 Digital Preservation Terminology and Concepts

One challenge in discussing solutions to the problem of technology responsiveness by the digital preservation community is that the terminology of digital preservation has not yet been formalised for universal use. For example, The International Standards Organization (ISO) working group on Digital Repository Audit and Certification (RAC) conducted a review that documented the absence of existing definitions for digital preservation. This group is developing the digital archive certification standard via ISO TC20/SC13 (Space data and information transfer systems) and the working arm for the standards initiative is the Consultative Committee for Space Data Systems (CCSDS). [2] Preserving digital content involves participants from all sectors, including government, corporate, and academic; a range of professional domains, including archives, museums, and libraries; and other communities, including digital curation, information technology, and any community that produces digital content. As the authors of a community guideline for digital preservation noted, each of these different domains and communities has "a distinct vocabulary and local definitions for key terms".[3] A goal of this research

[2] The author of this thesis has been a member of the RAC working group and was a participant in those discussions. Digital Repository Audit and Certification (RAC) Working Group, email messages, 24 September – October 26, 2007.
[3] RLG-National Archives and Records Administration Task Force, *Trustworthy Repositories Audit and Certification: Criteria and Checklist (TRAC) Ver 1.0* (Chicago, IL: Center for Research Libraries http://www.crl.edu/PDF/trac.pdf (accessed 10 May 2008).

was to address the technology responsiveness needs of the whole digital preservation community. Since the absence of universal terminology poses an obstacle for exchanging information about digital preservation developments and practice between institutions and individuals, this section proposes working definitions of relevant digital preservation terms as used in this thesis and identifies core digital preservation standards and practice to provide a baseline for the subsequent discussions.

The discussion of terminology must begin at the highest level with the meaning of *digital preservation*. Although informal definitions of the term exist, there is no formal definition of the term digital preservation from an authoritative source. There are several possible reasons for this absence of authoritative definition. First, there is no single authoritative source for the digital preservation community, e.g., no professional society yet, as Section 1.4 notes. One possible role of a professional society may be to produce and maintain authoritative definitions and glossaries. Community members represent a number of professions, including archivists, librarians, and museum curators all of which have their own professional societies. Second, the glossaries produced by national and international professional societies of the major domains within the community have aged and not yet been revised to include newer terms.[4] Third, consensus has not yet been reached across the community on the specifics and nuances in the definition of digital preservation. At its 2007 annual meeting, the Preservation and Reformatting Section (PARS) of the American Library Association (ALA) held a special session to discuss the community need for a definition of digital preservation. PARS proposed this short definition, “Digital preservation combines policies, strategies and actions to ensure access to reformatted and born digital content regardless of the challenges of media failure and technological change. The goal of digital preservation is the accurate rendering of authenticated content over time”.[5] Fourth, informal definitions that have been proposed in the absence of formal definitions have not been comprehensive enough to satisfy the needs of the broader community. One example

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[4] For example, the official glossary from the International Council on Archives was produced in 1988, although a new version is in development. See International Council of Archives, ‘ICA Appoints Its First Ever Fellow’, http://www.ica.org/en/2007/12/06/ica-appoints-its-first-ever-fellow (accessed 15 December 2007).
[5] ALCTS, ‘Definitions of Digital Preservation’, American Library Association (ALA), Association for Library Collections and Technical Services, http://www.ala.org/ala/alcts/newslinks/digipres/index.cfm (accessed 15 December 2007).

defines digital preservation as “the maintenance of digital material over the long-term with a view to ensuring continued accessibility”.[6] Like the PARS definition, this definition of digital preservation does not specify responsibility for preserving digital content or include the characteristics of continued access to digital content, for example.

The following working definition of digital preservation was developed for use within the context of this thesis: The term *digital preservation* encompasses all of the *activities* that are undertaken by a *digital curator* to ensure that the *digital content* for which the digital curator has responsibility is maintained in *usable* formats *over time* and can be made available in *meaningful* ways to current and future users. The definition is intended to encompass the purpose of digital preservation, responsibility for digital preservation, and the objectives of digital preservation. The paragraphs below elaborate on this core definition by defining terms that are highlighted in *italics* above.

Digital preservation is the responsibility of individuals, institutions, and communities that produce, use, or accept responsibility for maintaining access to digital content over time, i.e., for as long as the digital content is needed or wanted. There are no inclusive, specific, and concise terms for use within the digital preservation community to refer to individuals who specialise in digital preservation. There are terms that tend to reflect the organisational context in which an individual is working, e.g., *digital archivist* and *digital preservation librarian*, but these terms are not useful in broader discussions of digital preservation.

Lacking a more specific, concise, and widely used term for an individual who specialises in digital preservation, this research adopted the term *digital curator* to refer to individuals with responsibility for digital preservation, focusing on the digital preservation portion of the digital curation definition, rather than on the data curation portion. The Digital Curation Centre (DCC) defines digital curation as the combination of the two terms data curation and digital preservation.[7] The DCC

[6] UKOLN, ‘Good Practice Guide for Developers of Cultural Heritage Web Services’, http://www.ukoln.ac.uk/interop-focus/gpg/Preservation/ (accessed 15 December 2007).
[7] This definition was provided by Peter Burnhill, who served as acting director when the DCC was established. Peter Burnhill, interview by author, 25 May 2006. Burnhill’s definition is reflected in the

noted that data curation refers to actions taken to manage data and, through updates, add value to the data for users.[8] The increased use of the term digital curator has paralleled the introduction of the term digital curation by the DCC.[9] Within the context of this thesis, a *digital curator* is defined as anyone, including archivists, librarians, museum curators, information specialists in other cultural heritage contexts, and, increasingly, creators and users of digital content, who initiates or accepts digital preservation responsibility for specific content. Academic programmes that train digital preservation specialists have begun to use the term digital curator and job descriptions are being posted for digital curators, indicators that the term is becoming more widely used.

The number and variety of digital curators is increasing, as these examples demonstrate. The School of Information at the University of Michigan maintains a Web page on being a digital curator to guide students in selecting appropriate courses. School of Information, 'Pathways to Success: Digital Curator', University of Michigan, http://www.si.umich.edu/pathways/pdf/26.pdf (accessed 20 April 2008). The University of Manitoba posted a job description for a Digital Curator / Archivist in December 2007. University of Manitoba, job posting for digital curator / archivist, Manitoba Library Association, http://www.mla.mb.ca/ (accessed 15 December 2007).

For example, the *Digital Preservation Management: Implementing Short-term Strategies for Long-term Problems* workshop has surveyed more than 450 international participants from more than 20 countries, including most European countries, Australia, New Zealand, and Africa in addition to the USA and Canada, since the first workshop was presented 2003. The target audience of the workshop is digital curators, specifically managers that are responsible for digital preservation. The institutional affiliations of the participants include representatives from national and local government, non-profit, academic, and corporate institutions. The author

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JISC definition of digital preservation. JISC, 'Digital Preservation Briefing Paper', http://www.jisc.ac.uk/publications/publications/pub_digipreservationbp.aspx (accessed 20 April 2008).

[8] Digital Curation Centre, 'Frequently Asked Questions from Data Curators', http://www.dcc.ac.uk/FAQs/data-curator (accessed 20 April 2008).

[9] This 2004 paper included the role of curator in the DCC curation model. Philip Lord, Alison Macdonald, Liz Lyon, David Giaretta, 'From Data Deluge to Data Curation', presented at the e-Science All Hands Meeting 2004, Nottingham, September 2004, http://www.ukoln.ac.uk/ukoln/staff/e.j.lyon/150.pdf (accessed 20 April 2008).

of this thesis is a co-developer of the workshop curriculum. Anne R. Kenney and Nancy Y. McGovern, *Digital Preservation Management: Implementing Short-term Strategies to Long-term Problems*, workshop series, 2003-2007, http://www.icpsr.umich.edu/dpm/ (accessed 1 May 2008).[10]

Digital content refers to information that was created in or converted to digital form.[11] Digital content consists of a growing range and combination of information types, e.g., text, images, geospatial data, audio, and video. Throughout its lifecycle, digital content relies upon information technology of all kinds, including the following technology types:

- The *software packages* used to create, store, manage, process, and provide access to digital content,
- The *file formats* that are supported by those software packages at the time of creation and to which the digital content is converted over time as software packages and file formats are created and evolved,
- The digital *storage media* on which the digital content is stored at the time of creation and to which it is copied or moved over time,
- The combinations of *operating systems*, *computer programs*, *security mechanisms*, *computer hardware*, and *communication networks* that support and enable the creation, management, protection, and use of digital content over time,
- The *standards* for formats and practice that develop and emerge within the digital preservation, information technology, and other communities that are responsible for digital content as new information technologies become more widely used and stable

[10] For example see School of Information, 'Pathways to Success: Digital Curator', University of Michigan, http://www.si.umich.edu/pathways/pdf/26.pdf (accessed 20 April 2008); and University of Manitoba posted a job description for a Digital Curator / Archivist in December 2007. University of Manitoba, job posting for digital curator / archivist, Manitoba Library Association, http://www.mla.mb.ca/ (accessed 15 December 2007).

[11] All definitions in this thesis that cite the *Oxford English Dictionary* (OED) use the current online version that was last updated December 2007. Digital is defined as "of, pertaining to, or using digits [DIGIT n. 3]; spec. applied to a computer which operates on data in the form of digits or similar discrete elements". 'digital, a,' *OED Online* (Oxford University Press, December 2007) http://dictionary.oed.com/cgi/entry/50063921 (accessed 5 Jan. 2008). A digit is defined as "each of the numerals below ten (originally counted on the fingers), expressed in the Arabic notation by one figure; any of the nine, or (including the cipher, 0) ten Arabic figures". Source: 'digit, n.', *OED Online* (Oxford University Press, December 2007) http://dictionary.oed.com/cgi/entry/50063919 (accessed 5 Jan. 2008).

Digital content is dependent upon these layers and aspects of information technology, which are continually evolving, to be usable and meaningful for as long as access to the digital content is required.[12]

For digital content to be *usable* and *meaningful*, users must be provided with the means—human or automated—to find, open, read, and use digital content that is maintained by a digital preservation program. The 1996 *Preserving Digital Information: Report of the Task Force on Archiving of Digital Information* report identified five features of the integrity of digital content that digital preservation needs to address.[13] The authors noted that "in the digital environment, the features that determine information integrity and deserve special attention for archival purposes include the following: content, fixity, reference, provenance, and context".[14] The content feature of digital content integrity refers to ensuring that the "intellectual substance" of the content as defined by the significant properties of the digital content is preserved.[15] The fixity feature of digital content integrity requires that digital objects to be preserved are able to be identified and preserved as a "whole and singular work" and that any changes to the object are recorded.[16] The reference feature of digital content integrity refers to ensuring the means to uniquely identify and specifically refer to a digital object in relation to other digital objects across time.[17] The provenance feature of digital content integrity requires that the digital content be traceable to its origin, i.e., its point of creation, or, at minimum,

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[12] For a discussion of technology layers, see: John A. Zachman, 'A Framework for Information Systems Architecture', *IBM Systems Journal archive* 26, no. 3: 276-292; for definitions of information security concepts and terms is ISO/IEC 27001:2005*: Information technology - Security techniques - Information security management systems – Requirements* (Geneva, Switzerland: International Standards Organization and International Electrotechnical Committee, 2005): 2-3.

[13] Don Waters, and John Garrett, *Preserving Digital Information: Report of the Task Force on Archiving of Digital Information* (Washington, DC: The Commission on Preservation and Access and The Research Libraries Group, 1996), iii.

[14] *Preserving Digital Information*, 12.

[15] *Preserving Digital Information*, 12-13. For example, see Margaret L. Hedstrom, and Christopher A. Lee, 'Significant Properties of Digital Objects: Definitions, Applications, Implications,' in *Proceedings of the DLM-Forum 2002, Barcelona, 6-8 May 2002* (Luxembourg: Office for Official Publications of the European Communities, 2002), 218-27.

[16] *Preserving Digital Information*, 14-15. For example, the *TRAC* requirements identify checksums as an example of a fixity check for demonstrating that a repository monitors the integrity of digital content. OCLC and CRL, *TRAC,* 34, http://www.crl.edu/PDF/trac.pdf (accessed 10 May 2008).

[17] The report discusses the means available at the time to uniquely identify a digital object, including Uniform Resource Names (URN) and Uniform Resource Locators (URL), both of which were being formalised and implemented when the report was published. *Preserving Digital Information*, 15-16. Since 1996, there have been developments regarding what are now referred to as *persistent identifiers* for digital objects.

from the point of deposit in a trusted digital repository.[18] The context feature of digital content integrity ensures that for each digital object the technical dependencies, the linkages with other objects, the dissemination means and restrictions, and the social environment of the digital object in the form of policies and norms be preserved.[19] The Open Archival Information Systems (OAIS) Reference Model incorporates these five integrity features into its definition of Preservation Description Information (PDI).[20] The OAIS Reference Model was approved by the International Standards Organization in 2003.[21]

Over time refers to the length of time during which the digital content should remain usable for legal, financial, cultural, business, or other purposes. The span of time for which the retention of digital content is required or desired may be measured in months, years, decades, or centuries. Digital content that contains scientific or other specialised information may require specialised knowledge that users must possess and apply to their use of the digital content; digital curators are not expected to instil that specialised knowledge in users.

The *activities* digital curators engage in include explicitly identifying the digital content to be preserved; taking responsibility for bringing that digital content into a sustainable environment with a digital preservation regimen appropriate to the digital content; and ensuring that the digital content can be made available over time to authorised users. This portion of the definition for digital preservation uses more generic language to describe the activities in which digital curators engage because these activities are often identified using the terminology of a particular profession. For example, the process of identifying digital content to be preserved is typically

[18] *Preserving Digital Information*, 16-18. For example, the TRAC requirements include references to provenance in the discussion of authentication, audit of digital content packages, and required metadata. OCLC and CRL, *TRAC*, 22, 25-26, 28, http://www.crl.edu/PDF/trac.pdf (10 May 2008).
[19] The report discusses the various aspects of context for digital objects. *Preserving Digital Information*, 18-19. The Metadata Encoding and Transmission Standard (METS) is one example of a means to capture the distinct aspects of context. See for example: Rebecca Guenther and McCallum, Sally, 'New Metadata Standards for Digital Resources: MODS and METS', *Bulletin of the American Society for Information Science and Technology*, 29, no. 2 (2003): 12-15.
[20] The OAIS Reference Model capitalises the names of its functions, roles, and other concepts, e.g., Preservation Description Information and this convention is used throughout this thesis.See the definition of Preservation Description Information, Consultative Committee for Space Data Systems, Reference Model for an Open Archival Information System (OAIS), Blue Book: CCSDS 650.0-B-1, Washington, DC: National Aeronautics and Space Administration, January 2002, 1-12 http://public.ccsds.org/publications/archive/650x0b (accessed 25 May 2008).
[21] ISO 14721:2003. ISO 14721:2003: *The Open Archival Information System (OAIS) Reference Model*, Geneva, Switzerland: International Standards Organization, 2003.

referred to as “selection” or “collection development” in libraries, “collection development” in museums, “appraisal” in archives, and “records” or “retention scheduling” by records managers.[22] The OAIS Reference Model provided the most comprehensive and the first explicit definition and explanation of the activities of digital preservation.

OAIS identifies six higher-level activities performed by an archive, each of which consists of individual functions for performing that activity. *Ingest* describes the functional components needed for the secure acceptance and quality control of submissions to an archive.[23] *Archival Storage* explains the functional components that ensure the secure storage, management, and retrieval of the content of an archive.[24] *Data Management* delineates the functional components for the comprehensive accumulation and provision of administrative data about the operation of and documentation about the content of an archive.[25] *Administration* describes the functional components needed to develop, maintain, and apply the policies and procedures that are used to operate and coordinate the functions of the archive.[26] *Preservation Planning* details the functional components needed to develop and recommend standards, policies, procedures, and mechanisms for preserving the content of an archive.[27] *Access* includes the functional components to find and deliver content in an archive to authorised users.[28] The terminology defined by the OAIS Reference Model, which is increasingly used by the digital curators to

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[22] See for example Rowan Watson, ‘Collection Development Policy’, Victoria and Albert Museum, http://www.vam.ac.uk/nal/policy/index.html (accessed 15 December 2007); andThe National Archives, UK, ‘Guidelines for Appraisal and Disposal’, http://www.nationalarchives.gov.uk/documents/assessments-part3.pdf (accessed 16 December 2006).

[23] The development of OAIS began as an initiative within the National Aeronautics and Space Administration (NASA) in 1995 to address the digital preservation requirements of the space data program. The OAIS working group expanded into an international group with broad representation by digital curators of all kinds. The working group completed the final version of the OAIS Reference Model in 2002. The OAIS Reference Model is undergoing a review, the results of which will be available in 2008. CCSDS, *OAIS Reference Model,* 4-1.

[24] CCSDS, *OAIS Reference Model*, 4-1– 4-2. The Lots of Copies Keeps Stuff Safe (LOCKSS) Project introduced a means for managing distributed storage that has been very influential within the digital preservation community, initially within the librarycommunity and increasingly more broadly. For a detailed description of the LOCKSS approach see: Petros Maniatis, Mema Roussopoulos, T. J. Giuli, David S. H. Rosenthal, and Mary Baker, 'The LOCKSS Peer-to-Peer Digital Preservation System', *ACM Transactions on Computer Systems* (TOCS) 23, no. 1 (accessed February 2005): 2-50.

[25] CCSDS, *OAIS Reference Model*, 4-2.

[26] CCSDS, *OAIS Reference Model*, 4-2.

[27] CCSDS, *OAIS Reference Model*, 4-2.

[28] CCSDS, *OAIS Reference Model*, 4-2.

refer to preservation activities, enables discussions that cross the boundaries of the professions, domains, and sectors in which digital curators work.[29]

Digital curators devise and share *digital preservation strategies* in response to the changing requirements of new and enhanced technologies. Digital content is preserved for as long as needed using digital preservation strategies that are suited to the technologies used to create, enable the management of, and provide access to the digital content. According to JISC, "Digital Preservation requires not only the maintenance and disaster recovery procedures needed for securing the media and its contents … but also strategies and procedures to maintain its accessibility and authenticity over time".[30] A digital preservation programme is expected to identify the digital preservation strategies needed to preserve the digital content within the care of the programme.[31] The determination of appropriate strategies is based on factors such as: the types of and requirements for digital content that is preserved, the quantity and similarity of digital content preserved, and, to a lesser extent, the resources available to the digital preservation programme based on the costs of applying a digital preservation strategy.[32] There are no formal standards in place for any of the digital preservation strategies in use, although the application of the strategies is becoming increasingly formalised. These digital preservation strategies are discussed in the following paragraphs, and efforts to automate the strategies are noted in the descriptions.

The dominant digital preservation strategies include migration, normalisation, and emulation. The objective of these strategies is to enable digital content to be readable and understandable over generations of technology. As noted above, these strategies have primarily been applied as a means to avoid file format obsolescence. They do so by allowing the file formats to be read by contemporary

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[29] One example of a source that addresses the value of OAIS terminology is: Sarah Higgins, 'Using OAIS for Curation', briefing paper (Digital Curation Centre, 2006), http://www.dcc.ac.uk/resource/briefing-papers/using-oais-for-curation/ (accessed 10 February 2008).
[30] JISC, 'Digital Preservation and Records Management Programme', http://www.jisc.ac.uk/whatwedo/programmes/programme_preservation.aspx (accessed 16 December 2006).
[31] OCLC and CRL, *TRAC*, 13, http://www.crl.edu/PDF/trac.pdf (accessed 10 May 2008).
[32] See for example: Stephan Strodl, Christoph Becker, Robert Neumayer, and Andreas Rauber, 'How to Choose a Digital Preservation Strategy: Evaluating a Preservation Planning Procedure', *Proceedings of the 7th ACM/IEEE joint conference on Digital Libraries*, 2007, 29 - 38.

software.[33] Migration, for example, is “the process of converting data from an obsolete structure to a new structure to counter software obsolescence”.[34] *A Glossary of Archival and Records Terminology* provides this succinct explanation of the challenge presented by file format obsolescence:

> Format migration may involve changes in the internal structure of a data file to keep pace with changing application versions, such as migration from Word 95 to Word 2000. Or, it may involve a more radical change in structure, such as changes from one application to another, such as Word to WordPerfect. Making changes in a data structure places the original at risk, as the new structure may not accurately capture the form and function of the original.[35]

Media migration or refreshing is another preservation action that has sometimes been discussed in conjunction with format migration.[36] The review of the digital preservation literature documented that tracking changes in storage media has been the most commonly discussed response to technological change after avoiding file format obsolescence.[37] The digital preservation strategy called emulation refers to the “use of one system to reproduce the functions and results of another system”.[38] Jeff Rothenberg first introduced emulation as a strategy to the digital preservation community in 1995 and it is since been advocated by others in the community.[39]

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[33] Emulation may be used to move digital content from older file formats to newer file formats, although it is also used to replicate the entire software environment on which the digital content relies to enable the use of the digital content as it was originally created and used. See for example, Creative Archiving at Michigan and Leeds: Emulating the Old on the New (CAMiLEON), http://www.si.umich.edu/CAMILEON/ (accessed 16 December 2006); and Gregory W. Lawrence, William R. Kehoe, Oya Y. Rieger, William H. Walters, and Anne R. Kenney, *Risk Management of Digital Information: A File Format Investigation* (Washington, DC: Council on Library and Information Resources, 2000).

[34] Richard Pearce-Moses, ‘Migration’, *A Glossary*, http://www.archivists.org/glossary/term_details.asp?DefinitionKey=84 (accessed 15 April 2008).

[35] Pearce –Moses, ‘Format migration’, *A Glossary*, http://www.archivists.org/glossary/term_details.asp?DefinitionKey=?1791 (accessed 15 April 2008).

[36] Media migration moves digital content that is stored on one type of storage media to another type of storage media. Unlike format migration, media migration does not change the internal structure and should be achievable with no loss or damage to the digital content. Pearce-Moses, ‘Media migration’, *A Glossary*, http://www.archivists.org/glossary/term_details.asp?DefinitionKey=1790 (accessed 15 April 2008).

[37] Examples include: ‘Media Matters: Choosing the Most Appropriate Storage Medium’, *Records Management Bulletin* 123 (2004): 9; and Joe Straub, ‘The Digital Tsunami: A Perspective on Data Storage’, *Information Management Journal* 38, no. 1 (2004): 42-44, 46-48, 50.

[38] Pearce-Moses, ‘Emulation’, *A Glossary*, http://www.archivists.org/glossary/term_details.asp?DefinitionKey=83 (accessed 15 April 2008).

[39] See for example, Jeff Rothenberg, ‘Ensuring the Longevity of Digital Documents’. *Scientific American* 272, no. 1 (1995): 24–29; and Jeff Rothenberg, *Avoiding Technological Quicksand: Finding a Viable Technical Foundation for Digital Preservation,* (Washington, DC: CLIR, 1998); Raymond A. Lorie, ‘The UVC: A Method for Preserving Digital Documents - Proof of Concept’, Commissioned by the Koninklijke Bibliotheek (DenHaag: Koninklijke Bibliotheek, December 2002;

Emulation "aims to preserve the original software environment in which records were created. Emulation mimics the functionality of older software (generally operating systems) and hardware".[40] Normalisation "converts the record from its original format into an open, standards-based format".[41] Although it is often mentioned as a digital preservation strategy with migration and emulation, there are few discussions or definitions of normalisation in the literature.[42] These digital preservation strategies are the explicit response to technological change by the digital preservation community, which is most often defined as avoiding file format obsolescence.

The terminology defined in this section is used throughout the thesis. Additional terms required for specific discussions are defined where needed. These fundamentals of digital preservation provide a baseline of information about digital preservation objectives and requirements for the discussions of technology responsiveness for digital preservation in this thesis.

1.4 Emergence of the Digital Preservation Community

This section documents the emergence of the digital preservation community whose need for technology responsiveness is addressed in the research. In this thesis, references to the digital preservation community include any institution or individual in any organisational context in which participants have acknowledged formally or informally the intention of preserving digital content across one or more generations of technology. The emergence of the digital preservation community is traced back to 1996, the date of publication of the *Preserving Digital Information*

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and Jeffrey van der Hoeven, 'Emulation for Digital Preservation in Practice: The Results', presented at the International Conference on Preservation of Digital Objects (iPres) 2007 Conference in Beijing, China, October 11-12, 2007.

[40]US Government Accounting Office (GAO), *Information Management: Challenges in Managing and Preserving Electronic Records*. Washington, DC: Government Accounting Office (GAO-02-586), 2002, 45. For a succinct discussion of emulation see: Granger, Stewart, 'Emulation as a Digital Preservation Strategy', *D-Lib Magazine* 6, no. 10.

[41] National Archives of Australia, 'Tools for Digital Preservation', http://www.naa.gov.au/records-management/secure-and-store/e-preservation/at-NAA/software.aspx (accessed 15 November 2007).

[42] See Digital Preservation Testbed Project, 'XML and Digital Preservation', Digital Preservation Testbed White Paper (Den Haag: Digital Preservation Testbed, September 2002), http://www.digitaleduurzaamheid.nl/bibliotheek/docs/white-paper_xml-en.pdf (accessed 15 November 2007); and National Archives of Australia, 'Xena [XML Electronic Normalising for Archives]: Software for Digital Preservation', http://xena.sourceforge.net/ (accessed 15 November 2007).

report, which is an early and often-cited example of combining expertise from the domains of library, archives, and museums. This section first characterises the digital preservation community then, at the conclusion, places the digital preservation community within the context of related and external communities. The latter segment of the section illustrates overlap and dependencies between the digital preservation and other communities that have had an impact on the emergence of the digital preservation community.

To document the emergence of the digital preservation community, the research identified the commonly-used attributes of an emergent group. The framework defines four attributes of a group that enable a group to be identified and studied: membership, interaction among members, goals shared by members, and norms held by members.[43] Each of these characteristics is considered in relation to the digital preservation community.

For a group to demonstrate *membership*, "a person must think of himself or herself as belonging to the group and must also be recognized by other members as belonging to the group".[44] There are indicators that the digital preservation community has an increasing membership of digital curators who would identify themselves as members of the community and who are identified by the community as members. For example, a growing number of digital curators have a job title or description that references digital preservation, making these individuals identifiable explicitly as digital curators and implicitly as members of the digital preservation community.[45] An identifiable set of authors, conference attendees, researchers, and practitioners are engaged in digital preservation.

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[43] H. Andrew Michener, John D. DeLamater, and Daniel J. Myers, *Social Psychology*, Fifth Edition, (Belmont, CA, USA: Thomson-Wadsworth, 2004): 324.
[44] Michener, et al., *Social Psychology*, 324.
[45] Examples include: British Library, 'Digital Preservation', http://www.bl.uk/aboutus/stratpolprog/ccare/introduction/digital/ (accessed 20 May 2008); Shannon Zachary, email messages to author regarding University Library hiring review, September 2007.ICPSR, 'Digital Preservation at ICPSR', http://www.icpsr.umich.edu/dp/ (accessed 20 May 2008); Cornell University Library, 'Digital Preservation Officer', http://www.library.cornell.edu/iris/dpo/ (accessed 20 May 2008); Chris Erickson, 'Digital Preservation Matters', http://preservationmatters.blogspot.com/ (accessed 20 May 2008); University of Manitoba, job posting for digital curator / archivist, Manitoba Library Association, http://www.mla.mb.ca/ (accessed 15 December 2007).

Interaction among members specifically requires that "group members communicate with one another and influence one another".[46] The maturation of the digital preservation community is increasingly reflected in a growing body of relevant literature. The domains that compose the digital preservation community have included periodic articles in their literature about the challenges of preserving digital content— since the late 1960s in the case of archival literature.[47] The issue of the longevity of digital content that had been digitised emerged as a topic in the literature of the library domain in the 1980s.[48] The literature of museum curatorship has included digital preservation articles since the 1990s.[49] In addition to the mainstream publications in the professions that compose the digital preservation community, increasing numbers of publications since 1996 either highlight or are devoted to digital preservation issues, including *Ariadn*e , *RLG DigiNews* in the USA, Preserving Access to Digital Information (PADI) in Australia.[50] These are community-based publications that provide information and updates on research and developments pertaining to digital content. The *International Journal of Digital Curation* was launched in 2006.[51] As discussed in Section 1.3, digital curation includes digital preservation. The journal contains both community reporting and peer-reviewed articles. This represents a step towards formal literature for the digital preservation community.

Interaction among members is also supported by professional conferences— formal, scheduled events for exchanging current information by members. Several relevant professional conferences have come into being within the past five years. The Society for Image Science and Technology (IS&T) Archiving Conference has

[46] Michener, et al., *Social Psychology*, 324.
[47] For an early example in the archival community see: Morris Rieger, 'Archives and Automation', in Technical Notes, *American Archivist* 29, no.1 (1966): 109-111; and for an example of emerging archival practice see Margaret L Hedstrom. Archives & Manuscripts: Machine-Readable Records. (Chicago, IL: Society of American Archivists), 1984.
[48] For example, an early article in the literature of the library community noted that developments in new technology, e.g., videodiscs, may be used to conserve precious and fragile materials. Nancy Jean Melin, 'Serials in the '80s: A report from the field', *Serials Review* 7, no. 3 (1981): 80.
[49] In the museum literature, an interesting discussion of the issues is: Cynthia Goodman, 'The Digital Revolution: Art in the Computer Age', *Art Journal* 49, no. 3 (1990): 248.
[50] *Ariadne* and PADI began in 1996 and are still published. *RLG DigiNews* began in 1997 and ceased publication in 2007. The author of this thesis was a co-editor of *RLG DigiNews* from 2001-2006. *Ariadne*.; *Preserving Access to Digital Information (PADI)*, National Library of Australia, http://www.nla.gov.au/padi/ (accessed 2 April 2008); and *RLG DigiNews*, RLG [now OCLC].
[51] *International Journal of Digital Curation* is an open access journal. *International Journal of Digital Curation (IJDC)*, UKOLN, http://www.ijdc.net/./ijdc/issue/current (accessed 2 April 2008).

been held since 2004.[52] This conference series was initiated by the digital imaging domain and includes both general digital preservation sessions and image-specific preservation sessions. The Digital Curation Centre (DCC) has hosted conferences that include digital preservation topics on the programme, with international attendees since 2004.[53] The International Conference on the Preservation of Digital Objects (iPres) has been held annually since it began in 2004.[54] This is the first regularly held international conference that is entirely devoted to digital preservation.[55] The ongoing occurrence of these conferences since 2004 suggests measurable progress towards formalising the digital preservation community through an exchange of developments and practice.

Shared group goals require that "group members are interdependent with respect to goal attainment, in the sense that progress by one member towards his or her objectives makes it more likely that another member will also reach his or her objectives".[56] There have been ongoing efforts to define and encourage good practice that reflect shared goals for digital preservation since the mid-1990s.[57] Three community documents have formalised digital preservation practice. The OAIS Reference Model was developed with broad participation by digital curators and approved by the International Standards Organization (ISO) in 2003.[58] OAIS was developed to be applicable in any organisational context in which digital content is managed for the long-term. The *Attributes of a Trusted Digital Repository: Roles and Responsibilities* report addressed the implementation of OAIS

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[52] There is a Web site for all IS&T conferences that includes the archiving conferences. Society for Imaging Science and Technology (IS&T), 'IS&T Meetings Calendar', http://www.imaging.org/conferences/recentmeetings.cfm (accessed 2 April 2008).
[53] Digital Curation Centre ,'DCC Events,' http://www.dcc.ac.uk/events/ (accessed 2 April 2008).
[54] International Conference on Digital Preservation (iPres), http://rdd.sub.uni-goettingen.de/conferences/ipres/ipres-en.html (accessed 2 April 2008).
[55] The next iPres conference will be held next at the British Library in September 2008. iPres 2008, http://www.bl.uk/ipres2008/ (accessed 3 May 2008).
[56] Michener, et al., *Social Psychology*, 324.
[57] Examples include: Neil Beagrie and Maggie Jones, *Preservation Management of Digital Materials – the Handbook* (London: British Library, 2001) [now maintained online by the Digital Preservation Coalition, http://www.dpconline.org/graphics/handbook/acknowledgements.html (accessed 10 May 2008)]; and *Best Practices Guides: A Typology*, Canadian Heritage Information Network (CHIN, 2004), http://www.chin.gc.ca/English/Digital_Content/Digital_Preservation/bestpractice.html (accessed 10 May 2008).
[58] ISO 14721:2003:*OAIS Reference Model*, 2003. Institutions that participated in the development of OAIS include the Arts and Humanities Data Service (AHDS) of the UK, the Cedars Project , National Library of Canada, and the US National Archives and Records Administration. As an example, see the full list of participants: Archival Workshop on Ingest, Identification, and Certification Standards (AWIICS), October 13-15, 1999, http://nost.gsfc.nasa.gov/isoas/awiics/participants.html (accessed 10 November 2007).

by identifying prerequisites for an organisation to conform to OAIS.[59] Together, OAIS and the trusted digital repositories document define the full context for digital preservation, explicitly addressing for the first time both the organisational and technological aspects of digital preservation. In 2003, the OAIS working groups released the *Producer-Archive Interface – Methodology Abstract Standard* (PAIMAS) that was approved as an ISO standard in 2006.[60] PAIMAS delineates in detail the interaction between the producer that submits the digital content and the archive that accepts responsibility for preserving this digital content. These documents represent community guidance that increasingly defines shared goals in the form of prevailing practice for digital preservation.

Primary funding sources for a community's activities influence the focus and direction for the research and developments undertaken by that community. There have been ongoing and ad hoc funding programmes for digital preservation research and development since the mid-1990s. The funding programmes of the Joint Information Systems Committee (JISC) fund digital preservation research and development.[61] The US Library of Congress collaborated with the US National Science Foundation (NSF) to establish the National Digital Information Infrastructure and Preservation Program (NDIIPP) in 2002. This programme funds projects that will create a national network of preserved digital content.[62] In 2002, the European Union collaborated with the National Science Foundation (NSF) in the USA to develop a joint research agenda for digital preservation and the NSF hosted a workshop with the Library of Congress to develop a research agenda for digital preservation.[63] These research agendas were in part developed to help define and encourage funding programmes for digital preservation.

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[59] Research Libraries Group (RLG) and Online Computer Library Center (OCLC), 'Trusted Digital Repositories: Attributes and Responsibilities', (Mountain View, CA: RLG, May 2002 [now maintained by OCLC]), http://www.oclc.org/programs/ourwork/past/trustedrep/repositories.pdf (accessed 10 November 2007).

[60] ISO 20652:2006: International Standards Organization, *Producer-Archive Interface – Methodology Abstract Standard* (Geneva, Switzerland: International Standards Organization, 2006), http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=39577 (accessed 10 November 2007).

[61] JISC, 'Digital Preservation and Records Management Programme', http://www.jisc.ac.uk/whatwedo/programmes/programme_preservation.aspx (accessed 10 November 2007).

[62] National Digital Information Infrastructure and Preservation Program (NDIIPP), Library of Congress, http://www.digitalpreservation.gov/about/planning.html (accessed 10 May 2008).

[63] NSF and DELOS, *Invest to Save: Report and Recommendations of the NSF-DELOS Working Group on Digital Archiving and Preservation,* 2003, prepared for the National Science Foundation's

Shared norms require that "group members hold a set of normative expectations (that is, norms or rules) that place limits on members' behavior and provide a blueprint for action".[64] The certification requirements for digital archives and development of shared curriculum for digital preservation are two examples of norms for the digital preservation community. The OAIS Reference Model included a call for a certification process for digital archives to demonstrate the effectiveness of the implementation of an OAIS system for preserving digital content. In January 2007, the certification of digital archives became the focus of an international working group to develop an ISO standard via the ISO TC20/SC13 technical committee.[65]

The working group is using the *Trustworthy Repositories Audit & Certification (TRAC): Criteria and Checklist* that was published in 2007 as a starting point for its work.[66] The work on the certification standard is also informed by the Digital Repository Audit Method Based on Risk Assessment (DRAMBORA) toolkit developed by the Digital Curation Centre and Digital Preservation Europe (DPE), and the work of the nestor project in Germany.[67] For practitioners, a digital preservation curriculum development project began in 2003 to provide guidance for

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(NSF) Digital Library Initiative and The European Union under the Fifth Framework Programme by the Network of Excellence for Digital Libraries (DELOS), 2003, http://delos-noe.iei.pi.cnr.it/activities/internationalforum/Joint-WGs/digitalarchiving/Digitalarchiving.pdf (accessed 10 May 2008); and NSF and NDIIPP, *It's About Time: Research Challenges in Digital Archiving and Long-term Preservation,* Final Report Workshop on Research Challenges in Digital Archiving and Long-term Preservation, April 12-13, 2002, sponsored by the National Science Foundation, Digital Government Program and Digital Libraries Program, Directorate for Computing and Information Sciences and Engineering, and the Library of Congress National Digital Information Infrastructure and Preservation Program (NDIIPP), 2003, http://www.digitalpreservation.gov/library/pdf/NSF.pdf (accessed 10 May 2008). Seamus Ross and Margaret L. Hedstrom chaired the *Invest to Save* group and Hedstrom chaired the *It's about Time* group.

[64] Michener, et al., *Social Psychology*, 324.

[65] The Digital Repository Audit and Certification Working Group, http://wiki.digitalrepositoryauditandcertification.org/bin/view (accessed 10 May 2008). The author of this thesis is a member of that working group.

[66] The TRAC document was developed between 2003 and 2007 and defines criteria that should be addressed for a digital repository to be certified. The author of this thesis was a member of the task force that produced the TRAC document. OCLC and CRL, *TRAC*, http://www.crl.edu/PDF/trac.pdf (accessed 10 May 2008).

[67] DRAMBORA uses an evidence-based and risk management approach. 'Digital Repository Audit Method Based on Risk Assessment (DRAMBORA)', Digital Curation Centre (DCC) and DigitalPreservationEurope (DPE), http://www.repositoryaudit.eu/ (accessed 10 November 2007). The nestor project uses a coaching approach to help bring organisations into conformance with standards. nestor Working Group Trusted Repositories - Certification, *Catalogue of Criteria for Trusted Digital Repositories*, studies 8, Version 1(Frankfurt am Main : nestor c/o Deutsche Nationalbibliothek, 2007), http://www.langzeitarchivierung.de/index.php?newlang=eng.

managers responsible for digital preservation.[68] The Digital Preservation Coalition (DPC) and the National Archives of Australia are partners in this curriculum development project. The Digital Curation Curriculum project at the University of North Carolina at Chapel Hill is developing with an international advisory board an academic curriculum that includes digital preservation.[69] Certification and curriculum define measurable norms for digital preservation.

The digital preservation community has begun to exhibit examples of each of the four group attributes discussed in this section. Cumulatively, these indicators document the emergence, cohesion, and maturation of the digital preservation community. The development of standards, good practice, sound investments of resources, and terminology for digital preservation are good indicators of the maturation of the digital preservation community. Tracing the emergence of the community confirms that the community is viable and able to engage in collaborative strategies, e.g., the proposed approach to technology responsiveness.

The process of tracing the emergence of the digital preservation community also highlighted examples of intersections with other communities that informed this exploration of technology responsiveness for digital preservation It was first necessary to focus on the definition of the parameters of the digital preservation community, the group primarily served by the proposed approach to technology responsiveness. In practice, there is no hard boundary around the digital preservation community.

The attributes of a group, i.e., membership, interaction of members, common goals, and shared norms, that were used to study the emergence of the digital preservation community also provide a useful framework for considering the intersection of the digital preservation community with other communities. Members of, or contributors to the work of, the digital preservation community might also – or only – define themselves as members of the digital curation community or information technology community, for example. Digital preservation

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[68] The Digital Preservation Management workshop series was co-developed by the author of this thesis beginning in 2001. The workshops have been offered since 2003. *Digital Preservation Management*, http://www.library.cornell.edu/iris/dpworkshop/ (accessed 1 May 2008).

[69] The author of this thesis is a member of the advisory board for the project as of October 2007. Digital Curation Curriculum (DigCCurr) Project, University of North Carolina at Chapel Hill, http://ils.unc.edu/digccurr/ (accessed 10 May 2008).

teams typically include members of these and other communities, a fairly common example of interaction between members within and across communities. As demonstrated previously by the definition of digital curation, the digital preservation community is embedded in the broader digital curation community; therefore, these two communities share some common goals. Developments that occur around its edges have an impact on the digital preservation community, either directly, through explicit collaboration, and by osmosis, through the participation of members of multiple communities who bring their experience and perspectives into the community. Examining the standards and practice (or norms) of other communities, e.g., information technology, business, and content creator communities, was a continual and essential component of the research. The results of this examination are referred to throughout the exploration of technological change in Chapter 2 and the investigation of technology responses in Chapter 3, in particular. These results demonstrate the need for the digital preservation community to contribute to and benefit from the ongoing technology responsiveness efforts of other communities. Although the primary focus is on the digital preservation community, the developments, contributions, and perspectives of other communities represent an integral part of the thesis.

1.5 Extent of the Existing Technology Response

This section documents three aspects of the technology response by the digital preservation community: the acknowledgment by the community of the need to respond to technology, examples of the digital preservation community's response to technological change, and the gaps that remain in enabling a comprehensive response to technology.[70] Building on early voices that recognised the need to develop an effective response to technology, an explicit acknowledgement of the need by the community has been formalised over the past dozen years as evidenced by a series of community documents that contribute to the defining the scope and requirements of the problem. That acknowledgement has led to efforts to address the problem that offer preliminary steps towards a solution, but are limited in scope and outcomes. Tracing the extent of the response identified three distinguishable gaps

[70] The evaluation of technology watch implementations in Section 3.5 discusses some of these digital preservation examples in greater detail.

for the research to address. That the digital preservation community is still emerging contributes to the absence of a fully-formed response to technology.

1.5.1 The Need Acknowledged

The acknowledgement by the digital preservation community of the need to track and understand technological change began in the 1960s with recognition becoming more routine by the 1980s.[71] An address by the President of the Society of American Archivists in 1980 included an urgent call for responsiveness to technology developments: “The current revolution in information processing is inexorably changing our world and our work...” We must, he said, “alter our past behavior” and “fashion strategies to cope with both the opportunities and the problems created by this revolution… The craft aspects of our work leave us preoccupied with daily practices, a preoccupation often obscuring the need for new methods and techniques…We need research on the life span of the products of high technology”.[72] Soon after this call to action was issued, the preservation focus on products of high technology began to fix upon the problem of maintaining the accessibility of file formats and the life span of technology was defined as the duration of active use of a particular file format.

More than a decade later, the 1996 *Preserving Digital Information* report formally acknowledged the problems that evolving technology presents for preserving digital content.[73] The charge given to the task force was to identify the major challenges of, determine the barriers encountered in, and provide recommendations for the preservation of digital information.[74] The authors acknowledged that continually identifying, understanding, and responding to the opportunities and risks presented by rapidly changing technology are essential

[71] Section 1.4 on the emergence of the digital preservation community and Section 1.6 on the literature review document in greater detail the early examples and voices on digital preservation topics. Several examples are offered here, by way of introduction.
[72] F. Gerald Ham, ‘Archival Strategies for the Post-custodial Era’, *American Archivist* 44, no. 3 (1981): 207, 214-215. The archivist Margaret Hedstrom was another early proponent for focusing on emerging technologies. She identified the need for a research agenda to address the impact of technologies for the longevity of digital materials. Margaret Hedstrom. ‘Understanding Electronic Incunabula: A Framework for Research on Electronic Records’. *American Archivist* 54, no. 3 (1991): 334-354.
[73] The *Preserving Digital Information* report recognised the challenge of continually changing technology. *Preserving Digital Information*, 2.
[74] *Preserving Digital Information*, iii.

activities for digital preservation. They noted that “reading and understanding information in digital form requires equipment and software, which is constantly changing and may not be available within a decade of its introduction”.[75] In the report, the task force members suggested that the participants in the lifecycle management of digital content, including “selectors ultimately need to have a rich understanding of the software and hardware dependencies of candidate digital information objects so that they can factor the carrying costs for an object into their overall assessment of its value”. They warned that “such understandings remain in relatively short supply in some measure because the educational processes for weeding selection and technical skills still need to be devised and perfected”.[76]

The report cautioned “how readily we can lose our heritage in electronic form when the custodian makes no plans for long-term retention in a changing technical environment,” and identified four important digital preservation challenges, all of which pertain to the need for responsiveness to technological change.[77] These were: “avoiding technological obsolescence”; “migrating digital material over time”; “addressing legal and organisational issues”; and “fulfilling the need for deep infrastructure”.[78] These challenges remain relevant today and provide a basic measure of the progress within the digital preservation community towards responding to changing technology. A specific definition or scope of the term *technological obsolescence*—the avoidance of which has since become the most often cited reason in the digital preservation literature for monitoring technology developments—was not provided in the report.[79] The reference in the report to the need for the ability to “identify, define and incorporate solutions that contribute to the larger, common goal of preserving our cultural heritage” remains a basic objective of responding to technology for digital preservation.[80]

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[75] *Preserving Digital Information,* 2.
[76] *Preserving Digital Information,* 24.
[77] *Preserving Digital Information,* 3.
[78] *Preserving Digital Information,* 5-7.
[79] The LIFE Project results are important step towards acknowledging the need to respond to technological change. The project results define monitor technology as an annual process to identify formats at risk. Additional examples are identified in Section 1.5.2. R. McLeod, P. Wheatley, and P. Ayris, ‘Lifecycle information for e-literature: Full report from the LIFE project. Research report’ (London, UK: LIFE Project, 2006): 4, 94-95.
[80] *Preserving Digital Information,* 8.

In 2002, the release of the OAIS Reference Model to the digital preservation community provided the first and most explicit reference to the need to monitor technology and proposed a Monitor Technology function for digital preservation. The report defined the Monitor Technology function as responsibility for "tracking emerging digital technologies, information standards and computing platforms (i.e., hardware and software) to identify technologies which could cause obsolescence in the archive's computing environment and prevent access to some of the archives current holdings".[81] It is noteworthy that this description specifies the objective of monitoring technology as avoiding the obsolescence of known technologies upon which the technology environment of the digital repository and the content in the digital repository rely.[82] This interpretation of monitoring technology for digital preservation influenced the nature and scope of technology responses within the digital preservation community because so many repositories have been developed using the OAIS Reference Model as a guide.

In 2004, the report *Digital Preservation for Museums: Recommendations* specifically identified the need to establish a technology watch and specified the scope and services the envisioned technology watch would provide for its users.[83] This report, which contained the first and most comprehensive statement about community requirements for responding to technology for digital preservation, included this recommendation: "Implement a technology watch protocol to ensure that no media type, file format or standard becomes obsolete before objects associated with any of the above have been addressed sufficiently".[84] This recommendation provides some specific requirements for a technology response and illustrates the tendency within the digital preservation community to equate responding to technology with avoiding file format obsolescence.

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[81] The OAIS Reference Model document explicitly describes and explains each function and its interactions with other OAIS functions; it does not recommend or proscribe how an organisation should implement a particular function. CCSDS, *OAIS Reference Model*, 4-13 – 4-14.
[82] Section 3.5 discusses the monitor technology function as defined in OAIS in greater detail.
[83] Tim Au Yeung, *Digital Preservation for Museums: Recommendations*, commissioned by the Canadian Heritage Information Network (CHIN) (Ottawa, Ontario, Canada: Ministry of Public Works and Government Services, 2004): 17-18.
[84] The CHIN recommendation also identified a set of products and services for members that are discussed in the evaluation of technology watch examples in Section 3.5. Au Yeung, *Digital Preservation for Museums*, 18.

In June 2006, the Society of American Archivists (SAA) in the USA distributed a set of strategies to enable members to address technological change. They, too, concluded that "Rapidly changing information technologies challenge archival principles and practices, and demand increasingly effective leadership from the archival community to prevent loss of records and improve preservation of and access to modern archival records in all formats".[85] The SAA document went on to define a series of educational and information sharing activities to address this issue. Two recommended activities directly related to technology responsiveness for digital preservation were to "create an Archives Technology Web Portal and collaborative communication tools on the SAA website to provide up-to-date news and information on technology issues" and "co-sponsor an annual technology summer camp for the development and sharing of research relating to technology in archives and allied professions".[86] This recommendation underscores the challenge of technological change and identified the development of a response to technology as a still unmet need within the community.

1.5.2 Efforts to Respond to Technology

The 1996 *Preserving Digital Information* report provided both a milestone in the acknowledgement by the digital preservation community of the need to respond to technology and a measure of the efforts to respond to the challenges defined in the report. The migration of digital content across generations of technology was already practiced for digital preservation when the report appeared and has since been more formally developed as a preservation strategy by the digital preservation community, although there are still no established standards within the digital preservation community for applying or measuring the impact of the strategy on digital content. The intellectual property concerns that were raised in the report as a primary legal and organisational issue continue to be discussed as copyright and

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[85] This document was included in an email announcement from Executive Director of SAA, Nancy Beaumont to the SAA Leadership mailing list. The author of this thesis is a member of the SAA Leadership mailing list. Beaumont, Nancy, email to the SAA Leadership mailing list, 7 June 2006.
[86] Nancy Beaumont, email message, 7 June 2006. For a related activity; see Richard Pearce-Moses and Susan E. Davis, *New Skills for a Digital Era: Proceedings of a Colloquium sponsored by the National Archives and Records Administration, Sponsored by Archives and Public Records, 31 May – 2 June, 2006*, (Washington, DC: Society of American Archivists and the Arizona State Library, 2007).

related legislation evolves globally.[87] The research and development identified by the report as necessary to defining and establish "deep infrastructure" for digital preservation has begun to be addressed within the past several years.[88]

The steps the community has taken towards responding to technological change may be tracked in publications within the digital preservation community that have touched on technology response. The Digital Preservation Coalition produced four technology watch reports in 2004 and 2005 on preservation metadata, large-scale archival storage, institutional repositories in relation to digital preservation, and the OAIS Reference Model.[89] The reports provided background on selected technologies for digital curators. These reports raise awareness about specific technologies, but the reports are largely informational and therefore, do not assess the implications of the technologies for digital preservation or provide specific recommendations for responding to the technologies. The reports do identify some resources that were used in their production, but the lists are limited and do not provide an extensive list of technology-related literature for seeking additional information. The Digital Curation Centre produced three technology watch papers in 2006 on digital repository software packages.[90] As noted above, a pioneering technology response example with relevance for digital preservation was the DigiCULT Technology Watch Reports series produced in 2003 and 2004.[91] These were annual reports that identified six technologies that would have significant impacts for cultural heritage. The results were not specific to preservation

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[87] For a, example of a broader discussion of legal issues for digital preservation, see Peter Hirtle has taught a session on the legal issues pertaining to digital preservation in the Digital Preservation Management workshop series since 2003. Peter Hirtle, 'Legal Issues for Digital Preservation', in *Digital Preservation Management*, 2003-2006.

[88] Infrastructure for digital preservation has begun to be addressed by such funding programmes by JISC, within the broader context of e-science programmes within the European Union, by the Cyberinfrastructure program at the National Science Foundation, and by the NDIIPP program at the Library of Congress in the USA. JISC, Digital Preservation and Records Management Programme http://www.jisc.ac.uk/whatwedo/programmes/programme_preservation.aspx (accessed 25 May 2008); 'Towards a European Infrastructure for e-Science Digital Repositories', http://www.ndk.cz/akce/towards-a-european-infrastructure-for-e-science-digital-repositories (accessed 25 May 2008); 'Sustainable Digital Data Preservation and Access Network Partners (DataNet)', http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503141&org=OCI (accessed 25 May 2008); and National Digital Information Infrastructure and Preservation Program (NDIIPP), http://www.digitalpreservation.gov/ (accessed 25 May 2008).

[89] Digital Preservation Coalition (DPC), Technology Watch Reports, http://www.dpconline.org/graphics/reports/ (accessed 10 November 2007).

[90] Digital Curation Centre (DCC) Technology Watch Papers, http://www.dcc.ac.uk/resource/technology-watch/ (accessed 10 January 2008).

[91] *DigiCULT Technology Watch Reports*, February 2003, and February and December 2004, http://www.digicult.info/pages/techwatch.php (accessed 10 January 2008).

and did not recommend responses to technology for digital preservation, although the reports did consider issues for cultural heritage. Section 2.5 further considers these reports in the evaluation of technology watch examples.

Providing the means for individual organisations to incorporate the development of a response to technology as a mainstream activity is an important step towards the community as a whole becoming responsive. Although there were a few examples of earlier efforts, the results of the LIFE project represent the first formal inclusion of technology response costs for digital preservation.[92] The LIFE project, a joint project of University College London and the British Library to define the costs of preserving e-literature, explicitly includes the salary cost to conduct an annual technology or obsolescence watch to detect indications of the impending obsolescence of file formats that are stored in an archive.[93] The LIFE project limits the scope of the technology watch to file formats. Version 1.1 of the LIFE Model expands the scope of the watch to include the systems watch for "monitoring for the need to upgrade or update systems or hardware due to technology obsolescence" and the preservation watch to include the software to render and the technical environment of file formats.[94] The results of the second phase of the LIFE project are intended to elaborate on the preservation aspects of the formula.[95] These results are significant and groundbreaking within the established and still limited parameters of the response by the digital preservation community to technology.

Several projects have demonstrated aspects of the means to monitor file formats in an archive to avoid the formats' becoming obsolete. Most of these projects mention PRONOM, a file format and software registry that was developed

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[92] The LIFE Project began in 2005 and the second phase began in 2007. For earlier examples, see: Creative Archiving at Michigan and Leeds: Emulating the Old on the New (CAMiLEON), http://www.si.umich.edu/CAMILEON/ (accessed 10 March 2008); Nada Kol and Erik Oltmans, Comparison Between Migration and Emulation in Terms of Costs, *RLG DigiNews* 9, no. 2 (2005); and Slats, Jacqueline and Remco Verdegem, 'Practical Experiences of the Dutch Digital Preservation Testbed', *VINE* (The Journal of Information and Knowledge Management Systems) 34, no. 2 (2004): 56-65. The author of this thesis served as the Experiment Architect for the Dutch Testbed Project from 2000-2001.

[93] McLeod, Wheatley, and Ayris, 'Lifecycle information for e-literature', 4, 94-95.

[94] P. Wheatley, *The LIFE Model*, v 1.1., the LIFE Team, October 2007, 9-10, http://eprints.ucl.ac.uk/4831/1/4831.pdf (accessed 10 March 2008).

[95] Paul Wheatley, 'LIFE: Costing the Digital Preservation Lifecycle', presented at the International Conference on Preservation of Digital Objects (iPres) 2007 Conference in Beijing, China, October 11-12, 2007, http://ipres.las.ac.cn/program.jsp (accessed 10 March 2008).

and is maintained by The National Archives.[96] Preservation and Long-term Access through Networked Services (PLANETS) is a European project that is led by the British Library.[97] PLANETS conducted a review of preservation planning as defined in OAIS that included the Monitor Technology function.[98] The PLANETS project has demonstrated its approach for monitoring file formats to avoid obsolescence of digital objects and will extend its approach to include monitoring for repository-level technology in future phases.[99] The Automated Obsolescence Notification System (AONS) developed by the National Library of Australia provides a means for an archive to be automatically notified when file formats in its collections are in danger of becoming obsolete, based on rules defined by the archive and using information about file formats that can be extracted from services such as PRONOM.[100] The kopal Library for Retrieval and Ingest (KoLibRI) of the kopal project in Germany refers to receiving "a message from a technology watch service or format registry" (e.g., PRONOM) when a format needs to be migrated.[101] PRONOM and AONS are both referenced in *Digital Preservation Service Provider Models for Institutional Repositories: Towards Distributed Services* as the source for a technology watch as part of preservation planning.[102] The article entitled, "A Foundation for Automatic Digital Preservation," refers to PRONOM in the context of their proposed "obsolescence notifier" and "format detector".[103]

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[96] The first version of PRONOM was developed in 2002. The National Archives, UK, PRONOM, http://www.nationalarchives.gov.uk/pronom/ (accessed 10 March 2008). See also Jeffrey Darlington, 'PRONOM—A Practical Online Compendium of File Formats', *RLG DigiNews* 7, no. 5 (2003); and Adrian Brown, 'Automating Preservation: New Developments in the PRONOM Service', *RLG DigiNews* 9, no. 2 (2005).

[97] The Preservation and Long-term Access through Networked Services (PLANETS) project began in 2006. PLANETS, http://www.planets-project.eu/ (accessed 20 April 2008).

[98] B. Sierman, *Report on Comparison of Planets with OAIS*, PLANETS, October 2007. The author of this thesis was asked to review a draft of the report.

[99] Sierman, *Comparison of Planets with OAIS*, October 2007, 5.

[100] David Pearson, 'AONS II: Continuing the Trend towards Preservation Software Nirvana', presented at the iPres 2007 Conference in Beijing, China, October 11-12, 2007, http://ipres.las.ac.cn/program.jsp (accessed 20 April 2008).

[101] In German, kopal refers to the cooperative development of a long-term digital information archive project. See for example: Stefan Funk, Kadir Karaca Koçer, Sabine Liess, Jens Ludwig, Matthias Neubauer, 'kopal Library for Retrieval and Ingest (KoLibRI)', version 1.0, July 2007, http://kopal.langzeitarchivierung.de/kolibri/koLibRI_v1_0_documentation.pdf (accessed 20 April 2008); and Olaf Brandt, 'Experiences from the kopal Project', http://www.iwaw.net/05/brandt.pdf (accessed 20 April 2008).

[102] Steve Hitchcock, Tim Brody, Jessie M.N. Hey , and Leslie Carr, 'Digital Preservation Service Provider Models for Institutional Repositories: Towards Distributed Services', *D-Lib Magazine* 13, no. 5/6 (2007).

[103] Miguel Ferreira, Ana Alice Baptista and José Carlos Ramalho, 'A Foundation for Automatic Digital Preservation', *Ariadne* 48 (July 2006).

1.5.3 The Gaps Addressed by the Research

These projects have demonstrated to the digital preservation community how technology can be used to address an obvious digital preservation need to avoid obsolete formats. File formats were the first and most obvious priority for efforts to combat technology obsolescence because file formats are the most basic unit in which digital content is stored and preserved, a characteristic that also makes this objective the most attainable of the possible objectives within technological change. Although file formats represent a relatively simple form of technology, achieving this level of familiarity with file formats required several decades of effort by the domains within the digital preservation community. The community, through its cumulative research and development efforts, has made significant strides towards monitoring and responding to changes in file formats to avoid obsolescence. These projects, however, neither address the need to assess nor provide a means to monitor and respond to technology developments that are more complex than file formats, such as digital objects containing multiple types of file formats, information systems that create and manage digital content, and software and other technologies that support or enable the functions and services of an OAIS system. The accomplishments to date with file formats provide a tactical solution to a particular aspect of the problem of technology obsolescence, a base of lessons learned in responding to technology, and a starting point for exploring more fully and systematically technological change as it pertains to digital preservation, but there is a pressing need to go beyond.

The review in this thesis of current responses to the problems posed by technological change for digital preservation identified three specific gaps in existing research and developments to be addressed. The first gap is the limited scope of interest for monitoring and responding to technology developments. The second gap is the tendency to limit the technology response for digital preservation to the avoidance of obsolescence. The third gap is the absence of an accepted approach within the digital preservation community for detecting, evaluating, and responding to the implications of technology developments for digital preservation. The research identified three aspects of technology responsiveness reflected in these gaps that should be specifically addressed: an optimal scope of interest for monitoring technology, a means to effectively assess the implications of detected technology developments for digital preservation, and a capacity for responding to relevant technological change in a timely and appropriate manner. The research discussed in this thesis and the technology response model produced by the research address these three aspects of technology responsiveness: monitor, assess, and respond.

1.6 Literature Review

Preserving digital content was a theme that ran through the literature of the archival, library, and museum domains, beginning for the archival community in the 1960s. This ongoing theme was supplemented in the 1990s by specialised community publications (e.g., *Ariadne*, *DLib Magazine*) that featured digital preservation articles. There is a growing body of peer-reviewed literature devoted to digital preservation topics, e.g., the *International Journal of Digital Curation*. The literature of the digital preservation community, inclusive of formal and informal sources, contains a spectrum of community-based documents, standards and guidelines, and formal publications.[104] As noted in Section 1.4, this mix of published and grey literature is characteristic of a community that is emerging.

As an emergent community, the formal and peer-reviewed literature of the digital preservation community is growing and community documents continue to perform an essential role in communication and the establishment of good practice among the members. The preceding sections of this chapter drew heavily upon community documents. The explanation of digital preservation fundamentals in Section 1.3 draws on core community documents and standards, e.g., the OAIS Reference Model, as well as relevant articles and reports that address the core digital preservation concepts. The discussion of the emergence of the digital preservation community in Section 1.4 primarily draws on examples of digital preservation

[104] The bibliography includes citations for the sources used in completing this research but does not reference all general and other sources on archives, digital preservation, and related topics that the author has consulted in the course of work-related and professional activities as a digital preservation specialist that parallel the formulation and completion of the research. This literature review includes published Anglophone resources that were available, either formally published or released electronically via a Web site, through October 2007 to include the proceedings of the International Conference on the Preservation of Digital Objects (iPres) held in Beijing, China.

research and practice, with some examples from the more formal literature. The review of the extent of the response by the digital preservation community to technological change in Section 1.5 traced the acknowledgement of the need for technology responsiveness within the digital preservation community and identified several gaps in technology response that this research addresses.

This section highlights two issues that were identified during the literature review: the lack of substantive technology or technology responsiveness discussions or examples in the formal literature of the domains within the digital preservation community and the absence of references to the literature of information technology and technology-related discussions in other domains. In each case, the issue of access to relevant information sources is considered as a contributing factor to these gaps.

1.6.1 Example: Technology References in the American Archivist, 1980-2000

To characterise the nature and extent of technology-related information available to digital curators within the literature of the emerging digital preservation community, this analysis focused on technology references in the *American Archivist* from 1980 to 2000. The *American Archivist* was selected as a useful and informative example for three reasons. First, the literature of the archival community began to address preservation concerns for digital content in the late 1960s.[105] Second, the journal is long-running, having been established in 1937, and the Society of American Archivists (SAA) continues to have a large membership base within the archival community.[106] Third, the author of the thesis is an American archivist and, therefore, most familiar with and better able to analyse American archival literature. The combination of the long track record of the archival community for preserving digital content, the existence of the *American Archivist*, and the broad SAA membership base offered the potential of a critical mass of citations for analysis. The results of this analysis were then broadened to consider the literature of digital preservation as a whole.

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[105] Meyer H. Fishbein, 'Appraising Information in Machine Language Form', *American Archivist* 35 (1972): 35-43.
[106] There are more than 5,000 individual and institutional members of SAA. Society of American Archivists, http://www.archivists.org/ (accessed 20 May 2008).

The analysis considered substantive discussions to include specific explanations of the nature and function of one or more existing or emerging information technologies, detailed discussions of methods or approaches for technology developments or implementations, more advanced discussions of technology that consider higher-level or complex topics, and recommendations regarding technology. References of any kind to technology were noted, and then the substance of the discussion was considered. Recognising that lengthy technical discussions may be beyond the mission and scope of archival journals, the inclusion of citations to information technology literature and other technology-related sources was noted. Two of the most common sources of information technology developments are the publications of the Institute of Electrical and Electronics Engineers (IEEE) and the Association for Computing Machinery (ACM). There are some citations to these two sources and there are numerous other technology-related sources that could be cited, but are not.[107] An underlying consideration in this process was that, in the absence of substantive discussions or citations directing digital curators to additional sources of information containing substantive discussions about technology, such curators would lack adequate information to develop coherent responses to technology developments.

The analysis of technology references in the *American Archivist* by category makes several trends very clear. Archival automation for description of archival records has been the most frequent subject of technology-related articles. The analysis of the American Archivist identified very few articles that address automating or integrating other archival functions. The rapid pace of technological change and its potential impact have been ongoing themes in the literature, but in general rather than specific terms. The list of articles identified in the analysis includes all references to technology-driven change and concern, the majority of which display an almost compulsory mention of the issue with typically no substantive discussion. References to the Internet began around 1995 and followed a similar pattern; the majority of those articles discuss considerations for using the

[107] Section 2.8 discusses the results of a review of technology-related sources using Ulrich's *International Periodicals Directory*, 1980-2005.

Internet for access and description, not for preservation of digital content and other recordkeeping issues.[108]

The *American Archivist,* like other professional journals, occasionally produces a special issue that is devoted to one topic. One issue on technological trends was entitled “2020 Vision”; it presented the papers delivered at the SAA meeting in Montreal in Autumn 1992. That issue also contained the first and only significant reference to object-oriented methodology during the period analysed.[109] The papers discussed technological, organisational, research, social, and cultural trends. While innovative, the papers are conceptual in nature and primarily serve to raise the issues, an important task at the time. Even the papers in the “2020 Vision” issue did not contain substantive discussions of technology.

Generally, the articles in the *American Archivist* that refer to or discuss technology do not cite information technology sources. The articles are more apt to cite library sources, management sources, or historical and other social science sources. For example, Bearman talks about data dictionaries, but mentions no data administration and database sources from which that concept is taken.[110] Some exceptions include Peterson citing the technology-related magazine *Datamation*; Kesner citing several office automation and microcomputer magazines; Benedict citing the *Journal of Systems Management*, without otherwise discussing technology; Dürr citing the *DEC Professional* magazine and also recommends articles to read; and Walch and Pederson providing technical citations.[111] The list of exceptions is brief.

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[108] For early examples see: Edie Hedlin, ‘Expanding the Foundation’, *American Archivist* 58, no. 1 (1995): 11-15; and Helen Tibbo, ‘Interviewing Techniques for Remote Reference: Electronic Versus Traditional Environments’, *American Archivist* 58, no. 3 (1995): 294-310.
[109] Ronald F.E.Weissman, ‘Archives and the New Information Architecture of the Late 1990s’, *American Archivist* 57, no. 1 (1994): 20-34.
[110] David Bearman talks about data dictionaries. David Bearman, Toward National Information System for Archives and Manuscript Repositories’, *American Archivist* 45, no. 1. (1982): 53-56.
[111] Trudy Huskamp Peterson, ‘Counting and Accounting: A Speculation on Change in Recordkeeping Practices’, *American Archivist* 45, no. 2 (1982): 131-134; Richard M. Kesner, ‘Microcomputer Archives and Records Management Systems: Guidelines for Future Development’, *American Archivist* 45, no. 3 (1982): 299-311; Karen Benedict, ‘Invitation to a Bonfire: Reappraisal and Deaccessioning as Collection Management Tools in an Archives - A Reply to Leonard Rapport’, *American Archivist* 47, no. 1 (1984): 43-49; W. Theodore Dürr, ‘Some Thoughts and Designs About Archives and Automation’, *American Archivist* 47, no. 3 (1984): 271-289; Victoria Irons Walch, ‘Innovation Diffusion: Implications for the CART Curriculum,’ *American Archivist* 56, no. 3 (1993): 506-512; and Ann Pederson, ‘Empowering Archival Effectiveness: Archival Strategies as Innovation’, *American Archivist* 58, no. 4 (1995): 430-453.

The analysis concluded that references to technology for the period of the *American Archivist* from 1980 to 2000 are mostly superficial, generally fail to provide access points to more technical sources in other fields, and are often well behind the invention, innovation, and even diffusion stages of relevant technologies. The literature review confirmed that this trend extends to other major archival and library journals. Only a sampling of museum literature was reviewed, but that sample reflected similar characteristics. One consideration regarding these observations is the question of differential access to information resources that may lead to the often infrequent references to technical sources by authors. Depending on the affiliation of the authors, they may or may not have had ready access to information sources that are licensed, private, or otherwise controlled and that may have limited their awareness or inclusion of technical sources. There is a small but significant stream of writers in the literature that provides exceptions to these findings, and there is an increasing interest in improving the provision of and access to literature on relevant technology. The research addressed the absence and timeliness of these discussions and references in developing the proposed approach. The survey of technology watch examples in Section 3.5 considers access to information sources underlying technology watch reports in its analysis. The research addresses the possibility that providing better access to technical sources – whether through citations, analyses, or direct access – would contribute to raising awareness and developing an understanding within the digital preservation community of relevant technologies.

1.6.2 Trends in Domain Literature of the Digital Preservation Community

To confirm and extend the results from the *American Archivist* analysis regarding technology-related discussions in the digital preservation literature, a review included major journals of the constituent domains within the digital preservation community since 2000. This review provided additional background on the emergence of the digital preservation community‘s response to technology developments. For example, the library community provided early voices on the use of technology for access to library materials using search techniques and strategies and for the most part joined the discussions of applying technology for preservation objectives in the 1980s when digitisation enabled the creation of digital collections that libraries were interested in preserving.[112] The literature of the museum community first reflected examples of the use of digital images to document collections, similar to the library community, then increasingly addressed the preservation needs of digital art, born-digital content to which the museum community is committed. In late 2006 *RLG DigiNews* had a special focus on digital asset management, a measure of the increased interest in technology for preservation within the museum community.[113] This extended review also confirmed the observations that discussions of technology-related topics are exceptional rather than routine, that the discussions are typically not substantive and that, when substantive, they are more explanatory than evaluative, and that technology-related articles are likely to cite archival, library, or museum literature rather than information technology literature.

These observations are based on an analysis of the existing content of the literature of the digital preservation community. The absence of access to technical sources detected by the review is addressed by this research in a number of ways. Section 2.8 considers the value and role of major types of information sources for technology developments in developing an understanding of technologies. Section 4.12 discusses the content component of the technology responsiveness model, indicating the information inputs and outputs of the model. Chapter 5 illustrates how information sources would be utilised to monitor, assess, and develop a response to a specific technology development. Section 6.4 imagines the ways in which various users of the implemented model would interact with its accumulated content in its itemised or aggregated forms. Cumulatively, these results propose an approach for the digital preservation community to address the perceived inadequacies of access to technical sources.

The literature review identified a series of gaps in the published literature of the digital preservation community pertaining to technology, technological change, and responding to technology as it evolves. For example, the research and developments that have been reported on to the digital preservation community

[112] See for example: Information Systems Consultants, *Videodisk and Optical Digital Disk Technologies and Their Applications in Libraries* (Washington, DC: CLR, 1985).
[113] The guest editor of the special issue described the scope and purpose of the special issues in this article: Günter Waibel, ed., ‘Special Issue Introduction: Managing Digital Assets in US Museums’, *RLG DigiNews* 10, no. 6 (2006).

about technology responsiveness have been limited in scope to investigations that address implications of technological change for existing file formats, have been limited in focus to the objective of avoiding the obsolescence of existing technologies, and have reviewed the potential application of new technologies to address the research problem from within the scope of file formats and the focus on avoiding obsolescence.[114] These gaps suggest that digital curators either may not have adequate information to understand technology developments to enable the development of effective responses to technology as it evolves or that digital curators seek substantive information about relevant technology in the literature of other communities, for example, information technology literature. If the latter is the case, there are few indicators so far that digital curators are bringing the results of seeking external literature back to the literature of the digital preservation community.

The majority of the research necessarily utilised information technology and technology-related sources from outside the digital preservation community. The research for the exploration of technological change discussed in Chapter 2, the investigation of common responses to technological change discussed in Chapter 3, and the technology response example that illustrates the model discussed in Chapter 4 each included extensive reviews and intensive analyses of information technology literature and technology-related literature from other domains. The research discussed in those chapters examined technology-related literature in other domains, including accounting, business planning, business management, computer science, economics, education, environmental studies, history of technology, information science, philosophy of technology, sociology, technology assessment, technology forecasting, and technology transfer. The types of sources used in that portion of the research included textbooks, technical journals and articles from academic and other research sources, journals and articles with a business perspective, project and professional Web sites of all kinds, and other sources that emerged in newspapers, the popular press, weblogs, and other results of Internet searching. The results from the investigation of technological change include an analysis of the nature and value

[114] The few exceptions to this characterisation of relevant research and developments in the digital preservation community are identified in the discussion of results of a survey of technology watch examples in Section 3.5, and none of those exceptions have results in more comprehensive results for digital preservation.

of the spectrum of available sources on technology developments in Section 2.8. These kinds of technology topics are not covered substantively and these sources are not cited extensively in the digital preservation and related literature. That portion of the research is mentioned here in the literature review and covered in detail in the relevant chapters.

1.7 Background for the Technology Response Model

As the review of the extent of the response to technology within the digital preservation community in Section 1.5 documented, file formats have been the most common focus of responses to technological change by digital curators, specifically the need and the means to avoid the obsolescence of existing file formats. That review identified gaps that this research addressed. First, there is a gap in the scope of interest in technology developments for digital preservation. Within the broad landscape of technology developments, the immediate priority and the scope of interest in monitoring and responding to technology for digital preservation has been file formats. This gap was addressed by the investigation of technological change, the results of which are discussed in Chapter 2. Second, there is a gap in the range of responses to technology for digital preservation. Defined by the scope of interest in technology developments, the response to technology by the digital preservation community has been largely limited to avoiding file format obsolescence. This gap was addressed by the investigation of technology responses, the results of which are discussed in Chapter 3. Third, there is a gap in the means to evaluate technology and respond to technology. This gap was addressed by the development of the technology response model for digital preservation discussed in Chapter 4 and the application of the model to the technology response example discussed in Chapter 5. What is needed is a model of technology responsiveness that addresses these gaps.

The first gap identified was the limited scope of existing technology assessment approaches within the digital preservation community. Using the basic definition of digital content discussed in Section 1.3, considering this gap began with the definition of a basic hierarchy of technologies that are used by digital curators for digital preservation to consider where this technology example fits in the hierarchy. Digital content consists of file formats and metadata that are stored as digital objects on digital storage media. Digital objects are typically grouped into collections of digital objects. Digital content is created using software, sometimes an individual software package and sometimes an information system. Digital content creators or digital curators typically manage digital content in an information system, called a digital repository. A digital repository is implemented by an organisation on a technology platform that consists of a combination of software and hardware. Placing the technology response example within this sequence, an object-based system is an example of a technology that might be used to create digital content to be preserved by digital curators and to preserve digital content that might have been created by other technologies. The research refined and extended this basic technology hierarchy to include other technological and organisational components, as discussed in Section 2.5 and Section 2.6.

The second gap identified was the lack of range of responses to technology. The review of the extent of the response to technology by the digital preservation community documented that the response has largely been limited to avoiding file format obsolescence. Unlike the application of digital preservation strategies that are of necessity developed in response to known technologies pertaining to existing digital content, potential responses to technology for digital preservation need not be limited to monitoring existing technologies to protect existing digital content from obsolescence. Formulating responses might begin, rather, with an exploration of a new or enhanced technology to consider both its opportunities and its challenges for future digital content and for digital preservation more generally, e.g., to enhance tools and procedures, to enable new repositories and capabilities, or to educate and train digital curators. The difference between the possible broader scope of technology responsiveness for digital preservation as envisioned here and accepted practice within the digital preservation community for responding to technology distinguishes the scope of this research from existing technology responses for digital preservation. A thorough study of a broader scope of the problem and the full range of potential solutions may produce beneficial and unexpected results; therefore, the larger scale of the problem is worth exploring.

The third gap identified was the absence of a comprehensive process to evaluate technology developments. The digital preservation strategies discussed in Section 1.3 have been developed by digital curators to preserve digital content that results from specific implementations of combinations of technology developments. The technology assessment applied to the technology response example was meant to be extensive and intensive enough to enable a digital curator to understand the range of possible implications of the technology for digital preservation. A comprehensive technology assessment should address more than the optimal preservation strategy for the types of digital content produced or affected by the technology to identify all of the opportunities and challenges presented by the technology. For example, the technology assessment would consider the broader implications the technology might have for the tools, the systems, the storage, and other aspects of digital preservation.

1.7.1 A Method of Technology Assessment and a Basic Model

The research sought existing approaches or examples to adopt or adapt for use in comprehensive technology assessments for digital preservation. Archival appraisal is a process that is familiar to the archival community and that has been applied to electronic records, a specialised form of digital content and a product of technology. This section considers the characteristics of appraisal that prevent it from being a means for conducting full technology assessments for digital preservation and the possible contributions of appraisal to enabling technology responsiveness for digital preservation.

Archival appraisal is "the process of determining the length of time records should be retained, based on legal requirements and on their current and potential usefulness".[115] The literature of the archival community has included ongoing discussions about the theory and practice of archival appraisal.[116] For electronic records, the process of archival appraisal is applied to individual instances of digital content – or records in this case – within a specific organisational and technological

[115] Richard Pearce-Moses, 'Appraisal', *A Glossary*, http://www.archivists.org/glossary/term_details.asp?DefinitionKey=3 (accessed 15 April 2008).
[116] Terry Cook, 'From the Record to Its Context: The Theory and Practice of Archival Appraisal Since Jenkinson', *Society of Archives Journal* 37 (1995): 32-52; Barbara Reed, 'Diverse Influence: An Exploration of Australian Appraisal Practice', *Archives and Manuscripts* 31, no. 1 (2003): 63-82; Robert Kretzschmar, 'Archival Appraisal in Germany: A Decade of Theory, Strategies, and Practices' *Archival Science* 5, no. 2-4 (2005): 219-238; and Carol Couture, 'Archival Appraisal: A Status Report', *Archivaria* 59 (2005): 83-107.

context.[117] The focus of appraisal is first on the content and then possible barriers presented by technology for preserving the specific set of records that is appraised. One experienced appraisal archivist wrote that, "the archivists considering the records to be appraised will study their age, volume, and form, and will analyze their functional, evidential, and informational characteristics".[118] Archival appraisal is applied to specific or categorical instances of electronic records that are the products of a particular combination of technology developments, e.g., an electronic recordkeeping system to track information about criminals identified and tracked by the Federal Bureau of Investigation as implemented using a version of a database software package.[119] Appraisal has been generalised to apply to categories of electronic records based on the content of the records, e.g., finance records, but not typically applied to categories of electronic records produced by general categories of technology.[120] Appraisals of electronic records view technology as a characteristic of the content, rather than as the focus of assessment.

The literature of the archival community has not included discussions of how archival appraisal might be applied to the assessment of technology developments more generally. The application of archival appraisal is too specific and applied at such a low and context-specific level to enable it to be used as a method to conduct full assessments of technology for digital preservation. Technology assessments for digital preservation should consider the cumulative results of appraisals of electronic records produced by relevant technologies. The recommendations produced by technology assessments should also contribute to the completion of appraisals of electronic records by informing appraisers about underlying technologies. Archival appraisal does not provide a process, produce results, or address technology in ways

[117] As a senior archivist at the US National Archives and Records Administration, the author of this thesis prepared more than two hundred appraisal reports of electronic records created by dozens of agencies in the US Government between 1986 and 1996 and was responsible for developing and maintaining the appraisal procedures used by the Center for Electronic Records during that period. This discussion is informed by that extended experience.

[118] Maynard J. Brichford, *Archives and Manuscripts: Appraisal and Accessioning,* Chicago, IL: Society of American Archivists, 1977.

[119] This is an example of an appraisal of electronic records completed by the author of this thesis while working as a senior archivist at the Center for Electronic Records of the National Archives and records Administration in the USA.

[120] Electronic mail is an example of a category of electronic records that has been identified by the generic computer application that produced the digital content, i.e., electronic mail software, but appraisals of electronic mail still focus on the content and purpose of messages and then on the specific technological environment that created the messages.

that would make it an effective approach to technology assessments for digital preservation.

To be broadly applicable and of greatest use, the technology assessment process would have to be able to consider generic characteristics that might be true of any implementation of the technology, rather than the specific characteristics of individual instances of a technology as appraisal does. A useful contribution appraisal offers for the development of an approach to technology assessment for digital preservation is an attention to the layers of context in which records exist. “There are five analyses that make up the basic tools archivists need in their appraisal kits to identify and select records of enduring value. These are an analysis: of a record's functional characteristics – who made the record and for what purpose; of the information in the record to determine its significance and quality; of the record in the context of parallel or related documentary sources; of the potential uses that are likely to be made of the record and the physical, legal, and intellectual limitations on access; of the cost of preserving the record weighed against the benefit of retaining the information”.[121] These appraisal analyses first consider the broadest context for the creation of the record, then the nature of the record, then the comparative importance of the record, and then the specific logistical considerations for preserving the record.

Building upon the concept of context from the appraisal process, the analysis for this research identified three layers of context that surround and would inform an assessment of a technology development. These layers identified a basic technology assessment model that was the starting point for the development of the comprehensive technology response model for digital preservation that this research produced. As with the analyses for archival appraisal, each layer of context for an assessment of a technology development defines types of information that would inform the assessment.

[121] Gerald F. Ham, *Selecting and Appraising Archives and Manuscripts*, Chicago, IL: Society of American Archivists, 1993, 51.

1.7.2 A Preliminary Step from Method to Model

The first layer of the basic model, general technology context, refers to the broadest landscape of the universe of information technology developments. The information at this layer would provide extensive background for the assessment. This layer might also identify technology developments that are not directly related to the specific technology development being evaluated, but that might have had an impact on the emergence of the targeted technology development. This layer replicates the analysis of the broader organisational context of the records in archival appraisal. Similarly, the technology assessment process would first seek to understand a new technology development by considering how it fits into its broadest context.

The second layer, the technology category context, refers to more specific and focused information about a major category of technology into which the target technology development fits. For the technology response example in this research, object-based systems, the technology category is information systems. This layer would provide intensive background about the technology category for the technology assessment. It would replicate the appraisal analysis to understand the nature of the records. This layer considers the components and elements that define the category as distinct from other categories, or the nature of the category. For this technology response example, the technology category layer would identify attributes that are present in any information system.

The third layer, category examples context, refers to information about new and emerging technology developments. This layer would enable a very specific analysis of the technology development framed by the attributes of the technology category. It replicates the appraisal analysis of related records or sources. A new technology in some way complements or extends the capabilities of existing technologies.

These contextual layers for a basic model for the technology assessment piece of a technology response are illustrated in Figure 1-1. Applying the basic model to a technology assessment would accumulate information for each context layer, moving from the outside to the inside layer, and repeat the process as new topics and issues that needed to be investigated were identified. As with archival appraisal, the information to be collected would include historical and current sources to situate the technology development in time and place and contribute to the understanding of the nature and characteristics of the technology development. The process would seek information in the sources of whatever domains discussed topics relevant to the assessment. These processes defined a starting point for developing the assessment component of technology responsiveness as illustrated by the contextual layers.

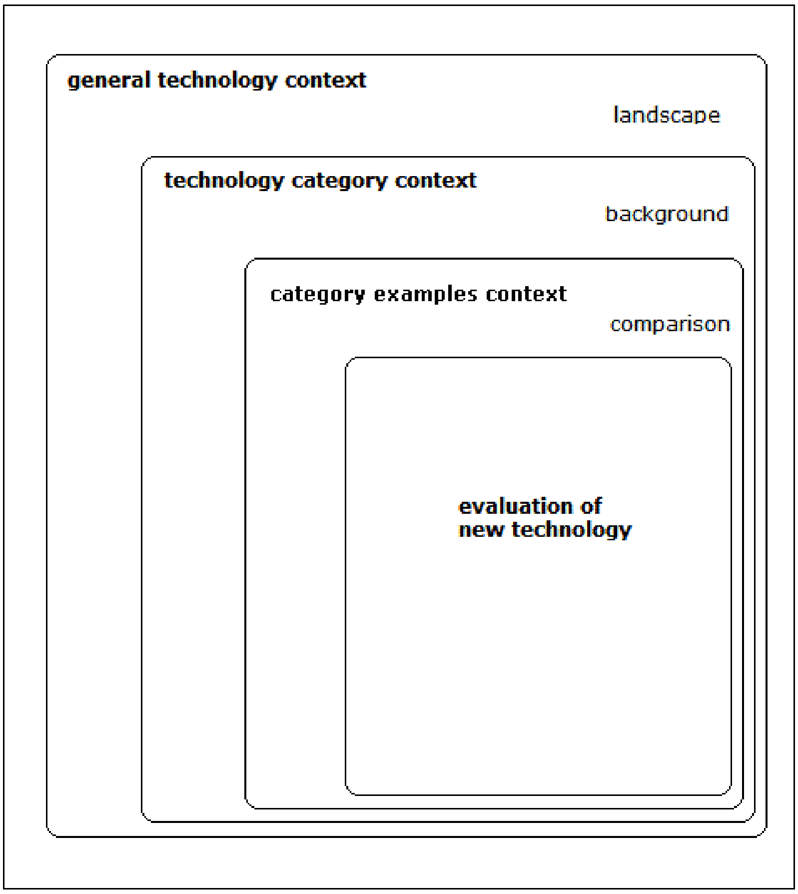

Figure 1-1. Contextual layers for a technology assessment.[122]

The technology response example, object-based systems, (see Chapter 5), demonstrated the application of the technology response model (Chapter 4), including the completion of a technology assessment.[123] Object-based systems

[122] The diagram in Figure 1-1 was developed by the author of this thesis.
[123] Object-based refers to the way in which the system stores digital content. Digital content may be stored as digital objects and managed by an object-based repository. Object-based systems utilise object-oriented principles, a computing "methodology in which a system is modelled as a set of

consist of a combination of technology developments that do not fit within the scope of existing approaches for responding to technology. Existing approaches do not define an adequate means for evaluating complex technologies, such as object-based systems. The research addressed this lack.

1.8 Research Methodology

The methodology for this research is exploratory because there has not been a comprehensive investigation of technology responsiveness within the digital preservation community that encompasses the full scope of technological change and the full range of its implications for digital preservation. The existing research on responding to technological change within the digital preservation community has been *limited*, according to the classification of exploratory research, because the research has largely focused on existing technologies, typically as they pertain to file formats, with the primary objective of avoiding obsolescence. Nor has there been a systematic study or the development of a comprehensive approach for responding to technology from another community that could be adopted for digital preservation purposes.[124] Exploration is appropriate for investigating topics that have not been systematically analysed, have been studied using a fixed rather than open-ended approach, or require renewed exploration due to significant change or development.[125] The first two rationales for undertaking exploratory research are applicable to technology responsiveness for digital preservation as a research problem because it has not been systematically investigated and to the extent that technology responsiveness has been investigated, the research has not been open ended. Although research is often classified as basic or applied, exploratory or confirmatory is a more useful classification within the context of this research because exploratory research might be basic or applied.[126] Whereas the purpose of

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objects which can be controlled and manipulated in a modular manner." 'object-oriented', *OED Online* (Oxford University Press, December 2007) http://dictionary.oed.com/cgi/entry/00329075se24 (accessed 5 Jan. 2008).

[124] Section 1.5 discussed the extent of the response to technology by the digital preservation community and Section 3.7 discuss the implications of technology responses from other communities for digital preservation.

[125] Robert A. Stebbins, *Exploratory Research in the Social Sciences*, Vol. 48, Qualitative Research Methods Series (Thousand Oaks, CA: Sage, 2001), 9.

[126] For example, basic or applied might characterise either exploratory or confirmatory research. Nunamaker, et al., explain the distinctions between confirmatory and exploratory research. Nunamaker, J.F., M. Chen, and T.D.M. Purdin, 'Systems Development in Information Systems Research', *Journal of Management Information Systems*, 7 (3), 1991: 90.

confirmatory research, the more commonly used type, is to support, refute, or extend existing knowledge, the purpose of exploratory research is to formulate knowledge and understanding of a new or substantially unexplored area.[127]

Despite acknowledgment within the community of the challenges of and the need to respond to technological change, the digital preservation community lacks any universal or even commonly used approach for achieving technology responsiveness. This exploratory research into technological responsiveness for digital preservation is classified as *innovative* because its aim was to produce a model for doing something in a different way.[128] Constructive research methodology was selected for this research on technology responsiveness for digital preservation because it is an exploratory methodology that formalises the development of products, including models. The primary purpose of constructive research methodology is to produce solutions to real problems.[129] This objective makes it ideally suited to the objective of this research, which was to develop a technology response model for the digital preservation community.

Constructive research methodology emerged in the 1990s and is slowly spreading by discipline and by geography.[130] Before discussing its development and characteristics, it is important to distinguish constructive research methodology from constructivist research, a qualitative form of research in which the research participates in observing social phenomena to understand how individuals or groups behave, largely through interviews. When the constructivist approach is used for exploratory rather than confirmatory purposes, it is investigative not innovative, in that it produces understanding that may result in theories rather than products, as

[127] Nunamaker, et al., 'Systems Development', 91.

[128] Stebbins classified four types of exploration: *investigative*, to establish a general understanding; *innovative*, to understand by testing or developing a product; *adventurous*, to discover typically through travel; and *limited*, to examine for a specific purpose. Stebbins, *Exploratory Research*, 2-3.

[129] One proponent of characterises the application of the methodology as using "existing knowledge and the addition of new technical advancements" to develop innovative solutions. Jonas Lindequist, and Daniel Lönnblom, *Construction of a Motion Capture System*, Reports from MSI, School of Mathematics and Systems Engineering, Vaxjo University, Sweden, 2004, 8.

[130] In addition to the domain examples cited below, researchers using constructive research are spread across several continents in an increasing number of countries. The examples cited reflect research conducted in Finland, Sweden, the UK, the USA and Australia.

constructive research does. [131] There is little similarity between constructivist research and the constructive research methodology, but the two are sometimes confused due to the similarity of the names.

Since constructive research methodology emerged within the last twenty years, the literature about it is not yet extensive, although there are increasing examples of its use. Constructive research has been widely used in computer science as well, although there has been less explicit definition and discussion of the methodology in that literature than in business. Constructive research is an exploratory approach that was explicitly defined within the business administration domain in a series of papers written between 1991 and 2003.[132] Constructive research methodology has been used in studying human computer interaction,[133] software engineering,[134] information science and technology,[135] economics, business administration and accounting,[136] design science, architecture, engineering, and urban planning.[137] The is use of the methodology is spreading into many domains.

Proponents of constructive research methodology cite the following reasons for a perceived slowness in the emergence of constructive research as a more widely

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[131] See Kathleen Fahy, and Karey Harrison, 'Constructivist Research: Methodology and Practice', in *Methods of Research in Sports Science: Quantitative and Qualitative Approaches*, editors Gershon Tenenbaum, and Marcy P. Driscoll, 2005: 681.

[132] Kari Lukka, 'The Constructive Research Approach', *Case Study Research in Logistics, Publications of the Turku School of Economics and Business Administration*, ed. Ojala, L. and O.-P. Hilmola, *Series B 1*, 83.

[133] See for example: Roope Raisamo, 'Multimodal Human-Computer Interaction: A Constructive and Empirical Study', (University of Tampere, 1999); Giarré and Jaccheri, 'Learning Research Methods and Processes via Sharing Experience in a BLOG', 44th IEEE Conference on Decision and Control and 2005 European Control Conference (CDC-ECC'05) (2005): 2716-20, http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=1582573 (accessed 25 May 2008).

[134] See for example: Lindequist and Lönnblom, 'Construction of a Motion Capture System'.

[135] See for example: Nunamker et al., 'Systems Development'; M. Pechenizkiy, S. Puuronen, and A. Tsymbal, 'On the Use of Information Systems Research Methods in Data Mining', in *Information Systems Development: Advances in Theory, Practice, and Education*, ed. Olegas Vasilecas, et al. (Springer, 2005); and Sari Viskari, 'Managing Technologies in Research Organization: Framework for Research Surplus Portfolio', in Tutkimusraportti 176 (Lappeenranta: Lappeenranta University of Technology, 2006).

[136] For economics, business administration and accounting examples see: Kasanen, E. and K. Lukka, 'Methodological Themes: the Problem of Generalizability: Anecdotes and Evidence in Accounting Research', *Accounting, Auditing & Accountability* 8, no. 5 (1995): 71-91; and T. Tuomela, 'On Bringing More Action into Management Accounting Research: Process Considerations Based on two Constructive Case Studies', *European Accounting Review* 12, no. 3 (2003): 409-42.

[137] For design science, architecture, engineering, and urban planning examples see: Salvatore T. March, and Gerald F. Smith, 'Design and Natural Science Research on Information Technology', *Decision Support Systems* 15 (1995): 251-266; Assessment of user-centred design processes as a basis for improvement action: Timo Jokela, 'An experimental study in industrial settings', 2001, Department of Information Processing Science, University of Oulu, Finland; and Shirley Gregor, and David Jones, 'The Anatomy of a Design Theory', *Journal of the Association for Information Systems*, Vol 8, Issue 5, Article 2, 312-335, May 2007.

used methodology to explain the dominance of confirmatory research; the lack of more examples in more domains to provide practical guidance for researchers; the characteristic – especially in business administration – for the results of constructive research to be kept internal to the sponsoring organisation; and the tendency for constructive research results to be longitudinal.[138] Because constructive research allows that technologies can be studied as "artificial constructs" and as social phenomena, it has particular relevance for the study of the human and technical aspects of technological responsiveness for digital preservation as a research problem.[139]

With the maturation of constructive research methodology, there have been efforts to characterise and classify its methods and results.[140] Lukka and Kasanen, early proponents of constructive research, identified four types of generalised outcomes resulting from the application of the methodology: "conceptual frameworks, which offer us the possibility to discuss the subject area in general; descriptive models, attempting to show 'how things are' in the problem field, covering more objects than the studied ones; explanatory models, which attempt to capture general relationships in the subject area; and prescriptive models, offering solutions to practical problems and guidance for further decision making in other similar, or corresponding organizations".[141] The technology response model proposed by this research matches the fourth type in their classification, a prescriptive model to achieve technology responsiveness for digital preservation. In another article they note that "all problem solving exercises do not pass as constructive research… an essential part of the constructive approach is to tie the problem and its solution with accumulated theoretical knowledge. The novelty and the actual working of the solution have to be demonstrated as well".[142]

March and Smith define an approach to constructive research that provided a method and evaluation criteria for this research. Their approach includes the construction of models using a combination of natural science and design science.[143] March and Smith note that natural science is "descriptive and explanatory in intent,"

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[138] Eva Labro, and Tero-Seppo Tuomela, 'On Bringing More Action into Management Accounting Research', 411.
[139] March and Smith, 'Design and Natural Science', 253.
[140] Gregor and Jones, 'Anatomy of a Design Theory', 312.
[141] Lukka and Kasanen, 'The Problem of Generalizability', 72.
[142] Kasanen, Lukka, and Siitonen, 'The Constructive Approach', 246.
[143] March and Smith, 'Design and Natural Science', 255.

while design science "offers prescriptions and creates artifacts that embody those prescriptions"; the combining of natural and design science thus provides a comprehensive research approach.[144] March and Smith defined natural science as a basic research method that is commonly used in physical, biological, social, and behavioural domains. They concluded that the objective of natural science is to develop a better understanding of reality through discovery and justification to test the discovery.[145] They identify four types of research products: constructs, models, methods, and implementations.[146] Of these four types of research products, models are the most relevant to this research, which produced a technology response model for digital preservation. A model has been broadly defined in the social sciences as something that "has a range of meanings and in some usages is indistinguishable from theory. It seems best described as a simplified representation of selected aspects of a phenomenon aiming to conceptualize and allow explanations of relationships to be framed and tested".[147] A model, which can be conceptual or mathematical, is further defined as an "artificial and abstract societal environment that represents its most important features".[148] March and Smith stipulate that the purpose of a model is "utility, not truth".[149] The technology response model passes their utility test because it addresses an actual problem: the need for digital preservation to continually respond to technological change. It also identifies the essential features of technology and its change cycle; optimises the functionality proposed or provided by responses to technology; and combines the resulting components into an adaptable model for responding to technological change.

The product of this research is the model for providing technology responsiveness for digital preservation; it was developed according to the principles of constructive research. Constructive research uses a "step by step procedure, so

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144 March and Smith, 'Design and Natural Science', 254.
145 March and Smith, 'Design and Natural Science', 254.
146 These four research products each have specific characteristics. Constructs "form the vocabulary of a domain. They constitute a conceptualization used to describe problems within the domain to specify their solution". A model is a "set of propositions or statements expressing relationships among constructs. In design activities, models represent situations as problem and solution statements". A method is "goal directed plans for manipulating constructs so that the solution statement model is realized". An instantiation is the "realisation of an artefact in its environment". March and Smith, 'Design and Natural Science', 253-254, 256, 258.
147 Patrick McC. Miller and Michael J. Wilson, *A Dictionary of Social Science Methods* (New. York: John Wiley & Sons, 1983), 72.
148 Michael S. Lewis-Beck, Alan Bryman, and Tim Futing Liao, eds., *The SAGE Encyclopedia of Social Science Research Methods* (Thousand Oaks, CA: Sage, 2003), 658.
149 March and Smith, 'Design and Natural Science', 256.

that the nature of the steps is specified in the framework system, within which the method is applied; the possibility exists to check every step or every phase of the construction. The procedure as a whole serves a definite purpose".[150] There are six steps in constructive research: [151]

1. Find a relevant practical problem with research potential
2. Obtain a general and comprehensive understanding of the topic
3. Build an innovative solution (or construct)
4. Demonstrate that the solution works
5. Show the theoretical connections and research contributions of the solution
6. Examine the scope of applicability of the solution

The use of this six-step process in the completion of the investigation of technology responsiveness for digital preservation is illustrated in Figure 1-2.

Research step	**Location in thesis**
1. Find a relevant research problem	Chapter 1
2. Obtain understanding of topic	Chapters 2 and 3
3. Build an innovative solution	Chapter 4
4. Demonstrate the solution works	Chapter 5
5. Show connections and contributions	Chapter 1, Chapter 6
6. Examine the applicability	Chapter 6

Figure 1-2. Mapping constructive research methodology to the thesis.

The technology response example completed for this research corresponds to Step 4 of this process. The technology response example suggests how the model would be used by the digital preservation community to develop an understanding of a new technology for developing an appropriate response to it.[152] The challenge in completing the technology response example while the technology continues to evolve and emerge is common in information technology and other kinds of

[150] Lukka Kasanen, and Siitonen,, 'The Constructive Approach', 258.
[151] Researchers using constructive research within the business administration domain typically add an extra step for developing a long-term relationship with the organisation that is studied. Lukka, 'The Constructive Research Approach', 83.
[152] One approach to understanding something is to be able to explain it. Explanation is a scientific process, to document that something exists, to explain what it is and why. Nicholas Rescher, *Scientific Explanation* (London: Collier-Macmillan, 1970), 3, 10.

coincident research because “the phenomenon itself is subject to change, even over the duration of the research study”.[153]

Constructive research was selected as the methodology for the research after consideration of several methodologies that were determined to be inappropriate. One methodology considered was grounded theory, an inductive process introduced in the 1960s and so named because the theory generated by the research process is considered to be grounded in the data.[154] A characteristic common to both grounded theory and constructive research is that some tactics for data collection and analysis are identified in advance, while others are developed later in the research process to match the research questions and the requirements of the methodology.[155] Since the purpose of this research was to produce a model that could solve a problem and not to develop a theory, grounded theory was not an appropriate methodology.

Case study methodology was also considered for the research. It was rejected as the methodology because although case studies might contribute to the development of a model, this methodology is not intended to result in a model. However, the research adopted three principles defined by case study methodology for collecting data: use multiple sources of evidence; create an evidence database containing notes, citations, narratives, tabular data, etc.; and maintain a chain of evidence.[156] Yin points out that the potential sources of evidence include documentation, such as mass media, formal studies, evaluations, and administrative information; archival records; interviews, which are generally open-ended; direct observation, participant observation, ethnography; life histories; and physical artefacts, which can include technological tools and instruments. [157] Case studies

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[153] March and Smith, ‘Design and Natural Science’, 255.
[154] The most oft-cited source for grounded theory is: Glaser and Strauss, *The Discovery of Grounded Theory: Strategies for Qualitative Research*. Chicago, IL: Aldine, 1967. Examples of grounded theory in the digital preservation community, including Stielow, ‘Archival Theory Redux and Redeemed: Definition and Context Towards Grounded Theory’, *American Archivist* 54, no. 1 (1991): 14-26; and Victoria Lemieux. ‘Competitive Viability, Accountability and Record Keeping: A Theoretical and Empirical Exploration Using a Case Study of Jamaican Commercial Bank Failures’, University of London, 2002.
[155] Berg, *Qualitative Research Methods*, 115, David Nachmias, and Chava Nachmias, *Research Methods in the Social Sciences*, 3rd Ed New York, NY: St. Martin’s Press, 1987), 301; Clive Seale, *The Quality of Qualitative Research: Introducing Qualitative Methods* (London: Sage, 1999), 91.
[156] Robert K. Yin, *Case Study Research: Design and Methods* (London: Sage, 1994), 79.
[157] Yin, *Case Study Research*, 79.

involve gathering information from a range of sources to gain a holistic picture of the phenomena studied.[158]

Action research was another methodology that was considered and rejected. Action research is research "conducted by a professional into their own activity with a view to bringing about an improvement in their practices".[159] While action research and constructive research both seek to develop an understanding of a problem, the outcomes of action research tend to take the form of guidance and recommendations rather than the more tangible solutions that are characteristic of constructive research.[160] Because the research discussed in this thesis involved an investigation of potential capabilities not yet in place in the digital preservation community, constructive research was a more appropriate methodology than action research.

Field research, another methodology that was considered, is an approach that involves "essentially immersing oneself in a naturally occurring set of events in order to gain firsthand knowledge of the situation".[161] This technology responsiveness investigation consolidated the "events" – in this case the existing practices for responding to technology already in use within the digital preservation community – as a starting point for the research and constructed a suggested framework for technology responsiveness, that is not yet naturally occurring in any environment. Ethnographic studies similarly define an approach for studying dynamic events that can be effective for phenomena when little is known about the subject in a particular domain.[162] Since technology responsiveness, which is inseparable from technology evolution, is a dynamic event, ethnographic studies would seem to have some relevance for technology responsiveness as a research problem. The investigation of technological change in Chapter 2 and the exploration of technology responses in Chapter 3, especially the evaluation of technology watch examples in Section 3.5, involved an analysis of information technology examples

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[158] See Martyn Hammersley, *The Dilemma of the Qualitative Method: Herbert Blumer and the Chicago Tradition* (London: Routledge, 1989), 93; and Yin, *Case Study Research*, 79.
[159] Graham Birley, and Neil Moreland, *A Practical Guide to Academic Research*, (London : Kogan Page, 1998), 34.
[160] Labro and Tuomela, 'On Bringing More Action', 412.
[161] Royce Singleton, and Bruce C. Straits, *Approaches to Social Research*, 3rd ed. (Oxford: Oxford University Press, 1999), 9, 353.
[162] Singleton and Straits, *Approaches to Social Research*, 321-324.

and sources. Both field research and ethnographic studies might have been used for the completion of step 2 of constructive research methodology (to develop an understanding of the topic). Although field research and ethnographic studies might have informed the investigations of technological change and technology responses, these approaches could contribute little to the development of the model. The structured steps of constructive research methodology did.

A combination of data analysis methods was used in this research, including content analysis and other methods involving text and document analyses.[163] This technology response model builds on the results of several content analyses that were conducted as part of this research. Section 1.6 summarised the results of an analysis of technology citations appearing in *The American Archivist* from 1980 to 2000. Section 2.8 summarises the results of an analysis of Ulrich's *International Periodical Index* to document the existence of technology references in relation to available sources. Sections 2.6 and 2.7 extensively discuss the results of an analysis of the OAIS Reference Model in order to explore and define the scope of interest in technologies for digital preservation. Section 3.5 refers to the results of an analysis of Institute of Electrical and Electronics Engineers (IEEE) sources to trace the nature and extent of the use of the term *technology watch*.

In addition to these examples of content analysis, the following examples illustrate the methods utilised in the completion of the research. Section 2.2 contains an explorative narrative of the nature of technological change using the literature of domains that discuss aspects of technology, its cycle of development and evolution, and its potential impacts. Sections 3.2 through 3.5 discuss the results of an analytical review of technology forecasting, technology assessment, technology transfer, and technology monitoring approaches for responding to changing technology using the literature of the domains in which these technology responses emerged and examples of technology responses. The bulk of Chapter 4 consists of the formalised expression of a model to enable technology responsiveness for digital preservation. Section 5.6 illustrates the results of an analysis of an emerging technology using

[163] Content analysis is a technique for studying documents that is often associated with grounded theory and that can be used for identifying the patterns in collected data. Bruce L. Berg, Qualitative Research Methods for the Social Sciences (Boston, MA: Allyn and Bacon, 1989), 4, 106-115.

evaluation criteria derived from an analysis of system methodology literature and examples.

The technology response model is intended to produce repeatable, extensible, and generalisable results for application to similar digital preservation problems. As Stebbins noted, “validity in exploration centers on the need to gain an accurate or true impression of the phenomenon under study. Reliability refers to replicability, to whether another researcher with similar methodological training, understanding of the research setting, and rapport with its members can make similar observations”.[164] Clearly documenting sources is one way to address concerns about the reliability and replicability of qualitative approaches.[165] Three steps of the constructive research process address the internal validity of the research: Step 2 (to obtain a general and comprehensive understanding of the topic); Step 3 (to build an innovative solution); and Step 4 (to demonstrate that the solution works). The final step (examine the scope of applicability of the solution) addresses the external validity of the research.[166] The criteria for evaluating models are the fidelity of the model in relation to the problem area, the completeness of the model, the level of detail that describes and explains the model, the robustness of the model in applying to real examples, and the internal consistency of the model.[167] Section 6.3 discusses the results of using these criteria to evaluate the technology response model for digital preservation. The technology response model for digital preservation was demonstrated by applying the stages of the model to the technology response example.

1.9 Limitations of the Research

No major studies or core resources document the landscape of technology responsiveness for this research to build on within the digital preservation community or within other communities, including information technology. There are sources on technological change and on many aspects of technology, but there has yet to be a comprehensive publication on technology responsiveness. As the literature review demonstrated, the references to technological change and

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[164] Stebbins, *Exploratory Research*, 25.
[165] Seale, *The Quality of Qualitative Research*, 141.
[166] Labro and Tuomela, ‘On Bringing More Action’, 415.
[167] March and Smith, ‘Design and Natural Science’, 261.

technology responsiveness within digital preservation sources have typically not been substantive or comprehensive. In addition, references within information technology literature have tended to be either implicit or cursory, although the examples of technology watch examples analysed in Section 3.5 show that there is no common implementation or approach in use for technology responsiveness within or across domains.

Resources and examples that were available by the end of October 2007 are included in this thesis. That cutoff date was set to include the presentations at the International Conference on Preservation of Digital Objects (iPres) 2007 Conference in Beijing, China, October 11-12, 2007. The status of the extent of the existing technology response discussed in Section 1.5 reflects developments that had been reported on by that date. This potential limitation is offset by a review that was conducted in preparation for the viva for this thesis in December 2008 confirming that the status had not changed.

The absence of sources has meant that more extensive explanations and background information than might typically be provided to set the stage and provide the foundation for key topics. This is especially true of the technological change and technology response discussions in Chapters 2 and 3. It would not be possible to provide a complete baseline of information for all of the potentially relevant topics that pertain to technological change and technology response, either broadly or specific to digital preservation, within the context of this thesis. Trying to establish that baseline was not an objective of this research. A challenge for presenting the research in this thesis has been to provide adequate information for the discussions and to highlight the most significant topics based on the results of the investigation. An effort has been made to limit explanations to the essential information required, to indicate the outcomes of analyses that led to the selection of the topics covered, and to provide pointers to additional sources for particular topics, which are located within the literature of many domains.

The research produced a model for responding to technological change from a digital preservation perspective. The investigation for this research was limited to categories of information technology developments that have potential implications for digital preservation. The research focused on a subset of information technologies that produce digital content and that provide mechanisms for enabling digital preservation over time, as discussed in Section 2.6. The proposed process for developing the high-level technology framework presented in Section 2.5 and the more specific technology inventory presented in Section 2.6 could be adapted for the development of a subset of technology developments for other aspects of digital information practice or for another community. The resulting technology response model demonstrates how digital preservation requirements are addressed by the approach, but the model was constructed to be generalisable and could be extended to other aspects of digital information lifecycle management, e.g., access services. Chapter 6 evaluates the contributions, validity, and repeatability of the research.

The technology response example, set out in Chapter 5, demonstrates the technology response model for digital preservation that was produced by the research and is discussed in Chapter 4. This is the valid means for meeting the evaluation requirement of constructive research when the research product is a model, but the application of the model can only be simulated. The thesis concludes that technology responsiveness is a shared responsibility within a community and that the community should enable technology responsiveness to serve its members. It provides an example to demonstrate the model with the expectation that the model would be fully implemented by the digital preservation community. The evaluation step of constructive research also occurs over an extended period as other researchers and practitioners engage with the results of the research. The means for others to evaluate the research product are discussed in Section 6.3. This research constraint is further offset by examples and references to potential implementation techniques and current examples that are discussed throughout Chapters 2, 3, and 4.

The thesis is for the most part limited to Anglophone resources, or to resources that were written in other languages and made available in English. An effort was made to include sources from the broadest range of English-speaking countries, but the countries of origin for the majority of resources include the United Kingdom, the United States of America, Canada, and Australia. The likelihood that relevant sources exist in other languages was underscored in the discussion of the research methodology because a number of proponents and developers of constructive research methodology are Finnish. In the case of the research methodology, it was possible to confirm that the key sources have been translated into English. This language limitation is based on factors such as the critical mass of resources, availability of resources, and the language skills of this researcher. Examples of technology responsiveness described in other languages may be useful in extending or enhancing the model.

1.10 Organisation of the Thesis

This thesis includes five chapters in addition to this introductory chapter. Chapters 2 and 3 consider the two core components of technology responsiveness: technological change and responses to technological change. Chapter 4 constructs and explores a model to enable technology responsiveness for the digital preservation community. Chapter 5 demonstrates the application of the model for the evaluation of a technology response example from a digital preservation perspective. Chapter 6 considers the outcomes, contributions, and future of the research.

Chapter 2, ‘A Digital Preservation Perspective on Technological Change’, discusses the exploration of technology and its evolution to address the first research question: *How would developing an understanding of the nature and cycle of information technology developments contribute to the development of an informed response by digital curators to ongoing technological change that is appropriate to digital preservation objectives?* Technological change consists of the accumulation of individual technology developments. The chapter discusses results from a sequence of analyses completed during the investigation of technological change to identify common characteristics of technology developments. Being aware of these characteristics would enable digital curators to detect the emergence of technology developments, to understand the natural cycle of technology developments, to track emerging technologies more effectively, to consider the optimal scope of interest in information technology developments for digital preservation, to develop criteria for identifying information technology developments that are potentially significant for digital preservation, and last, to evaluate the sources of information about technology developments in order to identify the best sources and uses of those sources for the digital preservation community. Annex 1, 'Detailed Results from the Scope of Interest Investigation', supplements the discussion of the nature of technology developments in Chapter 2 with results of these analyses that are too extensive to be included in the main text of the chapter.

Chapter 3, 'Adapting Technology Responses for Digital Preservation', explores and evaluates technology responses developed by the digital preservation and other communities to address the second research question: *How have communities responded to technological change and to what extent are existing models and examples of technological responsiveness effective for digital preservation*? This chapter discusses the results of an investigation of the four major technology responses identified: technology forecasting, technology assessment, technology transfer, and technology monitoring as well as the human response to technology. The investigation examined the scope, purpose, characteristics, and examples of existing technology responses. It concludes by considering the strengths and limitations of each response and the potential value of combining the technology responses for digital preservation. Annex 2, 'Profiles for Technology Watch Survey', provides full profiles of technology watch examples that contributed to the examination of technology monitoring in Chapter 3.

Chapter 4, 'Technology Response Model for Digital Preservation', discusses the development of the model to address the third research question: *What approach could be devised for use by the digital preservation community to continually detect, evaluate, and respond to changes in information technology that have potential implications for the long-term preservation of digital content?* The discussion of the model identifies, describes, illustrates, and explores the requisite stages for technology monitoring, assessment, and response that technology responsiveness entails. The description of each stage identifies current and emerging tools and techniques that would be appropriate to implementing the stages and steps of the model.

Chapter 5, 'Demonstrating the Technology Response Model', illustrates how the model would be applied to a technology response example and addresses the fourth research question: *How can the potential implications of the emergence of* *technology development be determined and evaluated to address digital preservation requirements?* The discussion of the technology response example walks through the model using the example to illustrate the inputs and outputs for each step of the six stages and the interdependencies between components of the model.

Chapter 6, 'Conclusion', discusses four major topics: a review of the research questions as addressed by the research; the evaluation of the technology response model using the criteria defined by constructive research methodology for evaluating models as research products; considerations for implementing the model for the digital preservation community; further research on technology responsiveness for digital preservation; and recommendations that resulted from the research. The chapter considers the results and contributions of the research.

Chapter 2. A Digital Preservation Perspective on Technological Change

2.1 Introduction

This chapter discusses the exploration of technological change to develop a better understanding of what technological change is to ensure that the digital preservation community is fully prepared to respond to its occurrence. The exploration included an examination of the existing scope of interest in technology developments for digital preservation in relation to the possible scope of interest in all technology developments to determine an optimal scope for the digital preservation community with respect to technology developments.[1] The research defines a scope of interest broad enough to avoid excluding technologies that might have implications for digital preservation, but narrow enough for the digital preservation community to address with available resources and expertise. The research results discussed in this chapter address the first research question on technological change, and the second step of the constructive research methodology, i.e., obtain a general and comprehensive understanding of the topic, in this case the technology component of technology responsiveness.

The research objective addressed in this chapter was to identify characteristics of a developing technology that might be detected and tracked and therefore responded to by the digital preservation community. The chapter begins by examining the concept of technological change and its characteristics as a foundation for the discussion. Subsequent sections focus on the development of a means to systematically identify, characterise, and prioritise types of technology developments that could be tracked as potentially relevant for digital preservation based on an analysis of the standards, requirements, and practice of the digital preservation community. The final section of the chapter considers available sources of information on technology developments for currency, content, value, and relevance.

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[1] Section 1.5 noted exceptions to this focus on file formats and some ongoing developments within the digital preservation community that are designed to address the technical environment in which file formats exist, for example. This research systematically considers the broad landscape of technology not limited to technologies that are known and already tracked.

In keeping with the principles of exploratory research, the exploration of technological change was open-ended.[2] Specifically, it included significant aspects of technological change in general – not limited to information technology – which might be relevant to technology responsiveness for digital preservation. It also considered relevant experiences of communities other than digital preservation.

2.2 Concepts and Characteristics of Technological Change

Developing a deeper and broader understanding of technological change provided a foundation for considering the scope of interest in technology developments for digital preservation. Although the digital preservation community acknowledges technological change as a challenge for digital preservation, the literature of the digital preservation community and its constituent domains has not reflected a sustained, comprehensive, and substantive discussion or analysis of examples of technological change and its specific implications.[3] To better understand technological change and enable an informed response to it, this section defines the term *technology*, discusses the distinction between science and technology, delineates the characteristics of technological change, and examines the types of technology developments.

A common definition of *technology* is "the scientific study of the practical or industrial arts".[4] In other contexts, including this thesis, the focus is on the products of such study, rather than on the study itself. A more useful and comprehensive source for the purposes of this research defines technology as objects or "physical devices of technical performance"; as knowledge about how technological innovation works; as the "skills, methods, procedures, [and] routines" of technological activities; as a problem-solving process; and as a "sociotechnical system" involving the "manufacture and use of objects involving people and other

[2] Section 1.8 on the research methodology identified and discussed the characteristics of exploratory research.
[3] Section 1.1 introduced the problem and Section 1.5 traced the acknowledgement of technological change as a digital preservation challenge. The literature review in Section 1.6 discussed the absence of technology discussions in the literature of the domains within the digital preservation community.
[4] 'technology', *OED Online* (Oxford University Press, December 2007), http://dictionary.oed.com/cgi/entry/50248096 (accessed 5 January 2008).

objects in combination".[5] All of these aspects of technology – its objects, knowledge, activities, process, and systems –have potential relevance for digital preservation in terms of understanding and responding to technology. The objects of technology may produce or sustain digital content to be preserved. An understanding of how technology works is essential for enabling digital curators to respond to technology. The characteristics and implications of the technological activities of digital content producers and users need to be understood by digital curators to facilitate digital preservation. In addition, digital preservation strategies are a form of technological activity that can be built or enhanced by new technologies. An awareness of the problem that a technology was intended to solve will assist in understanding the results and impacts of that technology and will allow the digital preservation community to adapt technologies developed by other areas for its own use. The interaction of people and objects in the development and use of technology has implications for the environment in which digital content was created and for the effective management of digital content over time. The broader definition of technology illustrates the complexities of responding to various forms and characteristics of technology.

Even in the digital world, learning about emerging technologies may begin as a craft, in which apprentices are trained in the use of new technologies. As technology evolves and becomes more complex, an apprenticeship is no longer adequate to keep up with the new technology.[6] The new technology becomes the domain of experts with more formal education and experience and takes on more of the characteristics of science.[7] Contrasting technology and science provides a useful insight into the nature of technology. Technology addresses the desire to do things; science addresses the desire to know things.[8] The discussion of the research methodology in Section 1.8 identified the process of constructive research as an

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[5] John Bilton, 'Technological Questions and Issues,' The UK Technology Education Centre, http://atschool.eduweb.co.uk/trinity/watistec.html (accessed 10 April 2008).
[6] R.A. Buchanan, *The Power of the Machines: The Impact of Technology from 1700 to the Present* (London: Viking, Penguin Group, 1992), 224-225.
[7] James K. Feibleman, 'Pure Science, Applied Science and Technology: An Attempt at Definitions', *Technology and Culture II*, 4 (Fall 1961): 35-38.
[8] This theme is addressed by several authors, for example: Feibleman, 'Pure Science, Applied Science and Technology', 33. Peter Checkland, *Systems Thinking, Systems Practice* (Chichester: John Wiley & Sons., 1981), 23.

effort to make the study of technology more scientific. For complex technologies, the line between technology and science may become blurred.

The term technology may encompass any kind of development that enables the ability to do something, but increasingly the term technology is used to refer to the more specific category of technology known as information technology. Information technology is “the branch of technology concerned with the dissemination, processing, and storage of information, especially by means of computers”.[9] Information technology developments are the primary focus of the digital preservation community’s interest in technological change. [10]

A simple definition of technological change is change resulting from technology.[11] More specifically, technological change may be understood as the accumulation of technology developments and the resulting changes in capabilities provided by the sum of technology developments. The accumulation of all technology developments covers a vast and growing range of domains and areas for advancements, even if the focus of interest is limited to information technology rather than the whole of technology. Examining the component parts of technological change – individual technology developments – contributes to a better understanding of technological change.

A technology development is a specific instance of advancement in the ability to do something, fitting into one of four categories for developments:

1. An enhancement to an existing capability for doing something that was already possible, i.e., the means for doing an existing thing better
2. An alternative to an existing capability for doing something that was already possible, i.e., the means for doing an existing thing differently
3. A new ability to do something that was desired, but not previously possible, i.e., the means for doing a new thing that was already a desired capability

[9] ‘information technology’, in ‘information’, *OED Online* (Oxford University Press, December 2007), http://dictionary.oed.com/cgi/entry/50116496/50116496se27 (accessed 5 January 2008).
[10] References to technology developments are information technology developments, except when noted.
[11] ‘technological’, *OED Online* (Oxford University Press, December 2007), http://dictionary.oed.com/cgi/entry/50248090 (accessed 5 January 2008).

4. An ability to do something that was not previously imagined, i.e., discovering the means for doing a new thing that was an unimagined capability[12]

Technology developments in any of these four categories may make it possible to achieve digital preservation objectives more efficiently or effectively, and therefore developments that fit into any of the four categories are potentially relevant to the digital preservation community.

Section 1.1 traced the acknowledgement by the digital preservation community of the challenge that technological change represents for digital preservation. The literature about technology demonstrates that expressions of concern about the rapid and continual pace of technological change are not limited to the digital preservation community and began decades ago. For example, in 1969, one technology author noted that “the rapid spread of sophisticated technology, particularly the automation of many work processes, has generated a series of alarms and prophesies”.[13] Technology and the impacts of technological change are large topics that may be studied from many perspectives, including technical capabilities and constraints, social impacts, historical view, industrial and economic factors, and governmental regulations and roles.[14] These examples

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[12] See for example: John Elster, *Explaining Technical Change: A Case Study in the Philosophy of Science*, Studies in Rationality and Social Change (Cambridge: Cambridge University Press, 1983), 95; and Ann Pederson. ‘Empowering Archival Effectiveness: Archival Strategies as Innovation’, *American Archivist* 58, no. 4 (Fall 1995): 430-453.

[13] Raymond A. Bauer, Richard S. Rosenbloom, Laure M. Sharp, and American Academy of Arts and Sciences Boston, *Second Order Consequences: A Methodological Essay on the Impact of Technology* (Cambridge, MA MIT Press, 1969): 20. One example of the prophesies Bauer referenced is the examples of potential developments in *The Computer Revolution*, including laboratory automation, early geographic information system applications, and the use of computers for games, music, arts, and information security, all of which have been achieved to some extent since. Nigel Hawkes, *The Computer Revolution* (London: Thames and Hudson, Ltd., 1971), 68, 71.

[14] Thomson observed that different domains view technological change differently. For example, economists view technological change as a process, business historians view technological change based on impacts on companies, and history of technology writers might focuses on the inventors of technologies. Nieto noted that the unit of analysis for studying technological change varies, as well. The unit might be society, an economic system, or industry, depending on the perspective. For an example from a management perspective, see Checkland, *Systems Thinking*, 73. For an example from a industrial perspective, see Buchanan, *The Power of the Machines*, 23. For an example from a social perspective, see Paul J. Lewis, *Information-Systems Development: Systems Thinking in the Field of Information-Systems* (London: Pitman, 1994), 64. For an example from a recordkeeping perspective, see David B. Gracy. ‘Archives and Society: The First Archival Revolution’. *American Archivist* 47, no. 1 (1984): 7-10. Ross Thomson, *Learning and Technological Change* (Basingstoke: Macmillan, 1993), 1. M. Nieto, ‘From R & D Management to Knowledge Management. An

demonstrate a broad interest in technological change across domains and identify domains with approaches that might be applied to digital preservation.[15]

A number of authors on technology noted that while there has always been technological change, the acceleration of change and the convergence of developments in many areas characterise this as an era of radical change.[16] The *information revolution* is defined as "the increase in the availability of information and the changes in the ways it is stored and disseminated that have occurred through the use of computers".[17] There is some debate about whether technological change should be described as evolutionary or revolutionary.[18] From either perspective, there is agreement that the introduction of new technology requires an adjustment in the techniques, processes, and mindsets by any community using the technology that has changed.[19]

Writers about technology describe the nature and path of large-scale technological change in varying ways. In 1980, Toffler defined characteristics of the three waves of technological change, which he labelled the First Wave, or the Agricultural Age; the Second Wave, or the Industrial Age; and the Third Wave, or the Information Age.[20] In describing the Information Age, he characterised and predicted the rapid changes in information technology of the past nearly thirty

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Overview of Studies of Innovation Management'. *Technological Forecasting and Social Change* 70, no. 2 (2003): 137.

[15] The types of community responses to technological change that may be relevant for digital preservation are explored in Chapter 3.

[16] Buchanan, *The Power of the Machines*, xiii; and Luciano Floridi, *Philosophy and Computing: An Introduction* (London: Routledge, 1999), 2.

[17] 'information', *OED Online* (Oxford University Press, December 2007), http://dictionary.oed.com/cgi/entry/50116496/ (accessed 5 January 2008).

[18] This debate has relevance for responding to technology because evolutionary change can be traced through iterative developments and revolutionary change would not be predictable and, therefore, could not be traced. Examples of authors that view technological change as evolutionary include: Thomson, *Learning and Technological Change*, 9; and Hedstrom, 'Understanding Electronic Incunabula', 342. Examples of authors that view technological change as revolutionary include Ithiel de Sola Pool, and Eli M. Noam, *Technologies without Boundaries: On Telecommunications in a Global Age* (Cambridge, MA: Harvard University Press, 1990): 7; Floridi, *Philosophy and Computing*, 54; and Buchanan, *The Power of the Machines*, xiii. The predictability of technological change is discussed in Section 3.2.

[19] See for example: Thomson, *Learning and Technological Change*, 2-3.

[20] Toffler noted the characteristics that describe the age also describe the developments that occurred as a result of that age. Alvin Toffler, *The Third Wave* (New York, NY: William Morrow, 1980), 35.

years.[21] Toffler's waves provided an early and vivid visualisation of the impact of the technological change he predicted.[22] It may be difficult to grasp that now-familiar developments were startling when Toffler predicted them. Within the past decade, authors have begun to identify emerging and future waves of technological change beyond the Information Age.[23] One objective of developing a comprehensive response to technological change for digital preservation is to provide the digital preservation community with a way to observe and understand these kinds of emerging patterns and trends.

Several important observations emerged during this exploration of technological change. The context of discussions of technological change is essential to understanding the intended scope, whether implicit or explicit. Technological change can be viewed on a larger scale, like Toffler's, as exemplified by the digital preservation community's approach to file formats and obsolescence (see Section 1.5). Even within a smaller scale, each technology development relies upon component and enabling technology developments.[24] Being responsive to technological change involves such a potentially large scope of technology developments that demonstrating responsiveness will require the establishment of boundaries to be able to specify the scope of technological change being addressed. The boundaries need to specify the characteristics and examples of technological change that are included and excluded in the definition of relevant technological change by an individual, an organisation, or a community.

Digital preservation has both retrospective and prospective requirements: to preserve the digital content produced by past information technology developments

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[21] Toffler's predictions including increases in the amount and types of digital information created, the growing reliance on digital information by organisations and individuals, increases in the capacity to store and exchange digital content, and developments in the ways in which digital content will be used and made available. Toffler, *The Third Wave*, 75, 187-188, 256, 260, 265, 268, 273, 379.

[22] One of Toffler's observations was that ages fade and new ages emerge, rather than ending abruptly. Toffler, *The Third Wave*, 35. This observation proved significant in the analysis of the technology response example, as discussed in Section 5.6.

[23] For example, Ahlqvist suggests that after the agriculture, industrial, and information societies are the biosociety (the current age) then the fusion society. Toni Ahlqvist, 'From Information Society to Biosociety? On Societal Waves, Developing Key Technologies, and New Professions', *Technological Forecasting and Social Change* 72, no. 5 (2005): 503-505.

[24] For example, the development and wide use of a file format requires software to create and use the file format, the evolution of a standardised file format specification, interoperability of the file format with commonly used software packages, the means to disseminate the file format.

while looking toward future information technology developments and to discover new or improved techniques for preserving existing and future digital content. The potential scope of interest for the digital preservation community might be any past, present, or future developments in information technology. A challenge for this research was to determine the characteristics of the relevant technology developments for digital preservation to be able to detect, monitor, prioritise, and respond to the most relevant technology developments.

2.3 Innovation and Technology Developments

Technology developments result from innovation and creativity, so developing an understanding of technology innovation may contribute to the ability of the digital preservation community to detect emerging technologies and to consider the potential implications of technology developments. Understanding the factors that encourage or inhibit innovation is of interest to organisations to be able to encourage and sustain innovation and to benefit from its results.[25] An ideal for technology responsiveness for digital preservation would be to select the technology developments that may have the greatest impact for digital preservation, e.g., identifying technologies that enable the most sophisticated digital content to be preserved or that produce the largest quantities of digital content to be preserved. One purpose in studying technology innovation is to be able to recognise and thus detect technologies that are emerging and increasing in popularity and use.

[25] Competing to be the first to develop a technology is one incentive for innovation. The convergence of the elements needed for a development to occur has led to some of the greatest technological competitions, e.g., to be the first to fly, to be able to communicate across the Atlantic Ocean, to be able to develop a machine that can perform mathematical functions more quickly and accurately than humans. Competitions within the digital preservation community regarding information technology developments include the automation of digital preservation activities to reduce the possibility of human error and decrease the cost of digital preservation, and the development of digital repositories that conform to the entirety of the *OAIS Reference Model*. The Digital Preservation Coalition established the Digital Preservation Awards in 2004 to recognise innovative developments. The 'Innovation Without Burnout' report is one cultural heritage example of understanding innovation to be able to benefit from the progress that innovation produces. This year-long study at Cornell University Library surveyed the staff for examples of innovation and completed case studies of units that exhibited innovative behaviour. Digital Preservation Coalition, 'The Digital Preservation Award', http://www.dpconline.org/graphics/awards/ (accessed 5 May 2007). Cornell University Library. 'Priority Team 9: Innovation without Burnout', 2005-06 Year End Report to LMT [Library Management Team], http://www.library.cornell.edu/staffweb/PriorityObjectives/docs/innovation_without_burnout_report.doc (accessed 12 October 2006).

A starting point for investigating technological innovation is the stages of innovation. The innovation stages are most commonly depicted by the classic innovation cycle characterised by three stages: invention, innovation, and diffusion, as represented in Figure 2-1.[26] *Invention* is the stage in the innovation cycle when a new idea, technique, product, or process is thought of or created.[27] *Innovation* is the stage of the innovation cycle that determines if the invention is practicable or scalable for wider use.[28] The objective of the innovation stage is to determine if the invention can be produced consistently and stably on a large enough scale to enable broad use. Another way to say this is that the innovation stage determines if an invention is able to be mass-produced. Inventions may not survive the innovation stage or may be delayed due to technology developments that are missing or slow to emerge, for example.[29] Moving from the invention to the innovation stage is similar to shifting from research to development; both transitions may involve new skills, teams, or organisations.[30] *Diffusion* is the stage of the cycle when the innovation is adopted or not by individuals and organisations.[31] The success of the diffusion stage marks the difference between a potentially good technology and a widely-used and popular technology.[32] The diagram of the innovation cycle displays the

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[26] Figure 2-1 is an adaptation of common visualisations of the innovation cycle, e.g., Buchanan, *The Power of the Machines*, 22. This adaptation of the innovation cycle diagram that highlights the decrease of occurrences from invention to diffusion was developed by the author of this thesis.
[27] For example, Thomson, *Learning and Technological Change*, 2-3; and Buchanan, *The Power of the Machines*, 23.
[28] For example, Thomson, *Learning and Technological Change*, 2-3; Floridi, *Philosophy and Computing*, 56-61.
[29] Other factors include the timing of the development in relation to the success of collaborations, market developments, the continued interest of key people in the innovation process. See for example: D.E. Kash, and R. Rycroft. 'Emerging Patterns of Complex Technological Innovation', in, *Technological Forecasting and Social Change*, 69, no. 6 (2002): 581-606.
[30] Just as people who are involved in a research project may not be involved in a development project that is based on their research, people who invent something may not be involved in bringing a development into production. The skills and interests required to invent something may be different from those needed to demonstrate the invention's utility in production. This is just one example of the nature of the shift and an indication of why every invention does not make it into production.
[31] For example, Thomson, *Learning and Technological Change*, 2-3; and Buchanan, *The Power of the Machines*, 26.
[32] A familiar technology development example is that although Beta videotapes were generally viewed as a better technology than VHS tapes, VHS defeated Beta in the market. For an interesting discussion of that example, see for example: Andrew Zinberg, and Mark Chase, 'The Battle between Beta and VHS', 1998: http://web.bryant.edu/~ehu/h364proj/sprg_98/chase/front.htm. Since that diffusion example occurred, DVD has replaced video tape cartridges and the competition in video-related developments has moved on to the competition between Blu Ray and HD. As early as 2006, Blu Ray was declared the market winner. Mark LePedus. 'Analyst Declares Blu-Ray the Winner'. Information Week (11 January 2006),

width of the arrows as decreasing to convey the winnowing process that occurs at each stage from invention to diffusion. There are fewer innovations than inventions, and fewer widely diffused technologies than innovations.

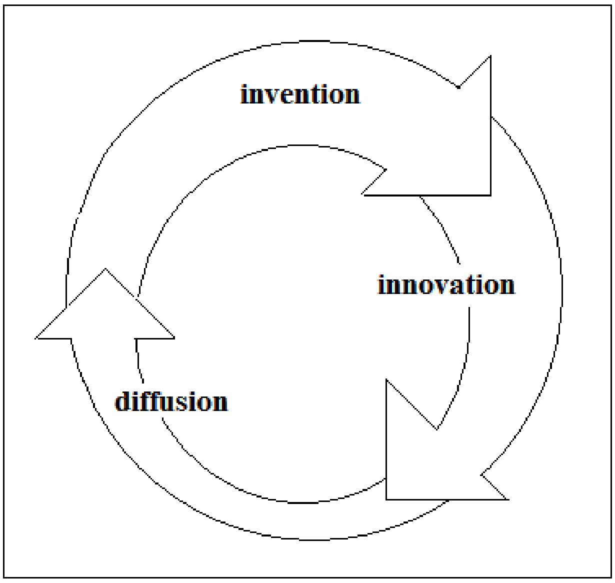

Figure 2-1. The innovation cycle for technology developments.

The innovation cycle is continuous because the process of developing invention *a* leads to other great ideas that become invention *b* and *c* and so on. Other parallel and unrelated inventions are also proceeding through the stages at varying paces. Disruptions in the cycle can occur before, during, or after any of the stages due to limitations such as undetected limitations in the capacity to produce the innovation, changeover in key researchers or developers, and limited availability of key components or materials.[33] A disruption can mean that an invention is never realised, or is delayed or aborted. The innovation cycle is a social as well as a technical process because the cycle involves human action and interaction.[34] The human side of innovation may make the timing and occurrence of innovation harder to predict.[35] There are human factors in both the development

http://www.informationweek.com/news/management/showArticle.jhtml?articleID=175803712 (accessed 10 June 2007).

[33] For example, Floridi, *Philosophy and Computing*, 56-61; and Buchanan, *The Power of the Machines*, xiii.

[34] For example, Elster, *Explaining Technical Change*, 112; and Buchanan, *The Power of the Machines*, 23.

[35] The human response to technology is discussed in Section 3.6.

and the use of technologies.[36] Expending all of the effort required to introduce a new technology does not ensure that people will like it or use it, or that organisations will invest in it.[37]

An information technology innovation example that has become familiar is the Internet.[38] In the invention stage, the Internet was mostly used by military and academic organisations with access to the technology.[39] Several factors combined to enable the transition of the Internet from invention to innovation, including the development of digital information to be exchanged, improvements in telephone lines, the establishment of an infrastructure for digital transmission, and a growing base of online users.[40] Two key developments enabled the diffusion stage for the Internet; the first development, Hypertext Markup Language (HTML), made the second development, the World Wide Web, possible.[41] The Web is cited as a technology development that seemed to emerge suddenly, although it consisted of a steady sequence of information technology developments in a variety of areas over a number of decades.[42] These examples suggest that it is possible to identify the

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[36] For example, Lewis, *Information-Systems Development*, 2; and Thomson, *Learning and Technological Change*, 2-3.

[37] The technology response example discussed in Chapter 5 considers the factors involved in the emergence of object-based systems as innovations. Yourdan, a prominent author on object-related topics, placed object-oriented methodology as entering the diffusion stage in the early 1990s, and object-based systems still have not achieved the domination that relational systems have had. Yourdan places object-oriented methodology in the early expansion stage in 1993. Edward Yourdon, *Decline and Fall of the American Programmer*, Yourdon Press Computing Series (Englewood Cliffs, N.J.: PTR Prentice Hall, 1993), 117, citing Everett Rogers *Diffusion of Innovations* 3rd ed, New York, NY: Free Press, 1982.

[38] Floridi concluded that the Internet was in the invention stage from 1968 and 1984. He identified three key developments that made the Internet possible: the ability to consistently transfer chunks of digital information from one computer to another, known as packet switching; the ability to structure information to allow one computer to receive and understand information from another computer, enabled by transfer TCP/IP standard that was approved in 1982; and the ability to uniquely name specific computers to allow for the controlled exchange and delivery of information between computers, made possible by the Domain Name Server (DNS) system. Packet switching was introduced in 1968 by the Advanced Research Project Agency Network (ARPANET), a military research project in the United States. Floridi, *Philosophy and Computing*, 56-61.

[39] Floridi determined that the Internet was in the innovation stage from 1984 to 1995. Floridi, *Philosophy and Computing*, 56-61.

[40] Floridi, *Philosophy and Computing*, 56-61.

[41] Floridi placed the Internet in the diffusion stage from 1995 forward. HTML is a subset of the Standard Generalised Markup Language (SGML), which began as the Generalised Markup Language in the 1960s. Web sites quickly overshadowed the more static, but popular, Gopher service that had been developed at the University of Minnesota in 1991. Floridi, *Philosophy and Computing*, 56-61, 76-79.

[42] A disruptive technology is one that “overturn[s] the traditional business methods and practices. For example, steam engine in the age of sail, and internet in the age of post office mail.” 'disruptive technology', BusinessDictionary.com. http://www.businessdictionary.com/definition/disruptive-

innovation stages of technology developments in hindsight, i.e., after the technology development has proceeded through the invention, innovation, and diffusion stages.

In digital preservation, storage media provide common examples of continual development and obsolescence of technology. Consider the emergence and demise of the three-and-a-half inch diskette and the zip drive, which occurred within the past several years. More recently, the flash disk, or jump drive, has become extremely popular for conveniently transporting large amounts of digital information. These storage media examples are significant for digital preservation because digital content has been or will be created, stored, maintained, and accessed using new and soon to be superseded technology. Emerging best practice is to retain synchronised copies of digital content on hard disks that are managed by one or more organisations in multiple locations.[43] Emerging examples of storage media might warrant a technology assessment to consider the implications for digital preservation based on the increasing or decreasing use of each media type. In addition to file formats, storage media represents a type of technology to be included in the scope of interest in technology developments for the digital preservation community.[44] The subsequent sections address the challenge of choosing which technology developments to invest in for digital preservation.

2.4 Examples for Adjusting the Scope of Interest

How might the digital preservation community define a framework to establish its scope of interest in technology developments? Models of the scope of interest in technology developments from other domains provide examples to evaluate for relevance to digital preservation.

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technology.html (accessed 2 May 2008). In one article, the Web is identified as the second most disruptive digital technology in the past twenty-five years. The most disruptive was identified as cell phones. Dan Tynan, 'The 10 Most Disruptive Technology Combinations, *PCWorld* http://www.pcworld.com/article/id,143474/article.html (accessed 2 May 2008).

[43] This represents a significant shift for archival storage management from offline to online storage. For example, the LOCKSS Project, introduced previously, contributed to this shift by providing a mechanism to manage distributed copies. A detailed description of how LOCKSS works is provided in: Maniatis, et al, 'The LOCKSS Peer-to-Peer Digital Preservation System':

[44] Sections 2.5 and 2.6 explore the scope of interest in technology developments for digital preservation in depth.

The business community has defined its scope of interest as technology developments that may result in positive business impacts and profits or negative business impacts and disruptions in the products and services businesses offer and the processes used to deliver those products and services.[45] To apply this business perspective to digital preservation, one can consider digital content as the product of digital preservation and its relevant products would include emerging types of repository software, file formats, or storage media that contain digital content. Preservation activities are the delivery processes in this analogy. Digital repository implementations have characteristics of both products and processes because repositories that contain digital content provide preservation services to enable digital preservation processes. Adapting the business perspective to digital preservation, the scope of technology developments of interest for digital preservation might be defined as changes that pose potential threats or offer potential opportunities for developing, managing, enhancing, or replacing these digital preservation products and processes. This example illustrates how a business perspective can be mapped effectively to digital preservation, although the analysis of this business model for technology innovations concluded that a more detailed classification is needed to actually adjust the scope of interest for digital preservation.

An international standards development initiative, the Joint Technical Committee (JTC) 1 Technology Watch project, defined an information communications technology (ICT) taxonomy for tracking technology development.[46] The JTC 1 technology taxonomy contains six layers of relevant technologies for information technology: social and cultural, processes and methods, human interfaces, Application Programming Interfaces (APIs) and

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[45]Harry Jones, and Brian C. Twiss, *Forecasting Technology for Planning Decisions* (London Macmillan, 1978), 26; and R. Phaal, C.J.P. Farrukh, and D.R. Probert, 'Technology Roadmapping - a Planning Framework for Evolution and Revolution', *Technological Forecasting and Social Change* 71, no. 1-2 (2004): 7.

[46] The JTC 1 is a joint committee of the International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC). JTC 1 is responsible for information technology standardisation. The JTC 1 Technology taxonomy is defined in a report presented by the committee, specifically in slide 24 of the committee's presentation. Coallier, François, 'JTC 1 Technology Watch Mandate and Objectives', ISO/IEC meeting, Université du Quebéc, École de Technologie Supérieure, February 9, 2003, http://standards.computer.org/sabminutes/2003Wint/JTC%201%20Technology%20Watch.ppt#263,24,ICT Taxonomy Model (accessed 14 May 2008).

middleware, hardware and devices, and base technologies.[47] The JTC 1 example suggests how a high-level scope of interest might be constructed as a framework for digital preservation and provides specific examples of technologies that might be associated with the categories within that framework. The evaluation of the JTC 1 example determined that the specific layers in the taxonomy focus on the foundation layer of technology for digital preservation upon which digital content might be created, managed, stored, and delivered.[48] This information technology perspective is instructive for digital preservation, but the JTC 1 categories are not a good fit for digital preservation because the taxonomy deconstructs the layers of information technology more specifically than is necessary for digital preservation and does not focus on layers that might address digital preservation requirements.[49]

2.5 Expanding the Scope of Interest

The high-level framework of technology developments discussed in this section uses the definitions of digital preservation terms in Section 1.3 as a starting point and is informed by the examples from other domains explored in Section 2.4. The specification of each technology-related category in the technology framework provides a rationale for the identification and inclusion of the category in the technology framework. It also suggests the kinds of technologies that relate to each category. The categories are rooted in good digital preservation practice as discussed in Section 1.3 on digital preservation fundamentals; in Section 1.4 on the emergence of the digital preservation community; and in Section 1.5 on the extent of the response to technology within the digital preservation community. The categories are object, collection, repository, platform, organisation, standards, and competencies.

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[47] The JTC 1 project identified examples of information technologies that are of initial interest for the project: storage, display, wireless, artificial intelligence, human computer interface, and quantum computing. Coallier, ‘JTC 1 Technology Watch’; and Subcommittee Chair’s Report on the 17th Plenary of JTC 1, Oct 21-25 2002, Sofia Antipolis, France, ISO/IEC JTC 1 SC24 N 2470.

[48] This comparison of examples from other domains and specifically the JTC 1 taxonomy to the interests of digital preservation identified the possibility that other communities are tracking technologies in ways that may complement but not duplicate the interests of the digital preservation community. The potential of shared monitoring topic is considered in Section 3.5.

[49] The layers of context required for a technology assessment were introduced in Section 1.7.

A digital *object* is a container for digital content and the basic unit of digital preservation. A digital object consists of digital content that is stored in one or more computer files in one or more file formats on one or more types of storage media.[50] A digital object also contains metadata, or information about the digital content, which is accumulated to describe, preserve, and provide access to the digital content.[51] The activities undertaken to preserve the digital object, e.g., the application of a digital preservation strategy, may retain the original version of the digital content and produce multiple versions of the digital content, each of which might be contained in the digital object.[52] Multiple copies of each digital object are required to ensure adequate redundancy for digital preservation and the copies may be stored on more than one type of storage media.[53] Technology developments associated with the object category include file formats and storage media to store and preserve digital objects, and the tools and techniques for the creation and storage of metadata to identify, manage, and use digital objects.[54]

Digital objects often belong to a *collection* or aggregate group[55] The ability to associate an identifier with digital objects and aggregations, i.e., the reference integrity feature, and always to be able to find and deliver digital content is a core

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[50] Digital objects may contain digital content consisting of multiple types of files, e.g., text, image, and audio files. The California Digital Library (CDL) defines a *complex digital object* as containing two or more content files with associated metadata. California Digital Library, 'Complex Digital Object', http://www.cdlib.org/inside/diglib/glossary/?field=glossary&action=search&query=oac (accessed 15 May 2007).

[51] CCSDS, *OAIS Reference Model*, 2-5 – 2-6.

[52] For example, the policies of the Florida Library Automation Center and the Inter-university Consortium for Political and Social Research (ICPSR) both explicitly state that the original versions digital content is retained for preservation. The author of this thesis developed the ICPSR policy. Florida Center for Library Automation, Florida Digital Archive (FDA) Policy Guide (FCLA, 2006), 6, http://www.fcla.edu/digitalArchive/pdfs/DigitalArchivePolicyGuide.pdf (accessed 10 June 2007); and Inter-university Consortium for Political and Social Research (ICPSR), Nancy Y. McGovern, *ICPSR Digital Preservation Policy Framework* (Ann Arbor, MI: ICPSR, June 2007), http://www.icpsr.umich.edu/DP/policies/dpp-framework.html (accessed 11 May 2008).

[53] The LOCKSS Project provides a means for distributed management of copies of digital content and the trading networks concept discusses the number of copies to maintain and other logistical issues. Maniatis, et al, 'The LOCKSS Peer-to-Peer Digital Preservation System'; Brian Cooper and Hector Garcia, 'Creating Trading Networks of Digital Archives', International Conference on Digital Libraries, *Proceedings of the 1st ACM/IEEE-CS Joint Conference on Digital Libraries*, Roanoke, Virginia, USA, 2001: 353 - 362.

[54] Section 5.6 of the object-based systems technology response example delineates features of object-based systems to conceptualise and manage digital objects.

[55] Examples of a collection or aggregation of digital objects include a series of institutional records created by a particular organisational unit, a manuscript collection of documents created by an individual, or an issue of a serial journal.

digital preservation objective.[56] Documenting and maintaining the relationships between digital objects are important requirements of digital preservation because this information provides the context for understanding the digital objects. The relationships between digital objects are defined by metadata used at the collection or aggregate level. Technology developments of interest at the collection level include those that enable or improve the generation, storage, and use of metadata about digital objects, about aggregations of objects, and about the relationships between objects and aggregations.[57]

A digital *repository* is an information system designed to contain digital aggregations and digital objects. A trusted digital repository is a specific implementation of an information system designed to meet digital preservation requirements. A trusted digital repository consists of software, tools, and modules developed to perform preservation activities for digital objects and aggregations. Technology developments relevant to the repository category include new or improved capabilities of software and programming languages to design, implement, and manage objects and collections within trusted digital repositories; tools and techniques to preserve new and enhanced types of digital objects and collections; and system tools and techniques to integrate, use, and protect new or enhanced storage media.[58]

A digital repository is implemented in some kind of computer environment, or *platform*, which includes the hardware and software, ensures adequate levels of security for the repository, and enables interoperability with other systems as needed. One platform may support multiple repositories with distinct requirements. The policies, procedures, practices, and standards that manage the platform are adapted to meet digital preservation objectives. Technology developments that are most relevant for the platform on which a repository resides include new and

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[56] This requirement is defined in *Preserving Digital Information*, 15-16; and CCSDS, *OAIS Reference Model*, 2-6, 4-27, and 4-35.

[57] Section 5.6 of the object-based technology response example references the capabilities of object-based systems for managing relationships between digital objects and aggregations.

[58] Section 5.6 of the object-based technology response example identifies key factors for evaluating types of information systems, or repositories, including the fundamental role of programming languages.

improved capabilities and capacities of hardware, software, computer networking, and security protocols and tools.[59]

A digital repository exists within the context of an *organisation* that has an interest in and relationship with the digital content in the repository. An organisation is subject to rules and regulations defined by, accepted by, and imposed upon the organisation.[60] The operation of the repository reflects the relevant regulations, mission, mandate, policies, procedures, standards, and resources of the organisation. Technology developments that are significant at the organisation level include techniques and tools to enable the development and application of policies and procedures and adherence to regulations within a trusted digital repository.[61]

Digital preservation relies on *standards* of all kinds to preserve digital content, to develop and operate trusted digital repositories, and to be interoperable with other trusted digital repositories and systems that provide specialised access to digital content. Standards enable common, consistent practices and remove or reduce the need for redundant efforts to develop individualised organisational responses. Standards in these environments may be de facto or formal, national or international, industry-specific or universal.[62] Awareness of emerging standards with relevance for digital preservation must be included as a factor in responding to technology. Standards for digital preservation include information technology, Internet, archival, and description standards.

Digital preservation requires the development and maintenance of *competencies* to identify, preserve, and provide access to digital content. Digital

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[59] Section 5.6 of the object-based technology response example identifies and discusses the importance of platform capacity and limitations for information systems.
[60] 'Digital Repository Audit and Certification Home Page'. http://wiki.digitalrepositoryauditandcertification.org/bin/view (accessed 5 November 2008).
[61] The PoLicy Enforcement in Data Grid Environments (PLEDGE) project within the DSpace Federation and the Preservation and Long-term Access through Networked Services (PLANETS) project funded by the European Union are current examples of efforts within the digital preservation community to develop or enhance policy application and enforcement capabilities. 'PLEDGE Project', http://pledge.mit.edu/index.php/Main_Page (accessed 10 November 2007); and PLANETS, 'Welcome to PLANETS', http://www.planets-project.eu/ (accessed 10 November 2007).
[62] The Open Archival Information System (OAIS) Reference Model is a prominent example of a standard that has influenced current digital preservation practice; it was introduced in Section 1.3 in the discussion of digital preservation fundamentals.

preservation requires familiarity with emerging technology developments as well as with older technologies that were concurrent with the creation of digital content. Information technology developments define the competencies required for digital preservation and offer the means to be aware of, to study, and to respond to relevant information technology developments. As technology developments emerge, are adopted, and are enhanced or superseded, the required competencies for digital preservation evolve in parallel.[63] Competencies for digital preservation include knowledge, skills, and experience in the areas of identifying or selecting digital content for digital preservation; preparing digital content for long-term preservation, including aligning the metadata with preservation metadata standards and ensuring well-formed digital content by adherence to format standards; and developing and applying appropriate digital preservation strategies.[64]

These seven core categories identified and analysed above have relationships and dependencies. Digital content is stored as digital objects that are organised into collections, or aggregations. Organisations commit to or rely upon digital content, in the form of collections and objects, which is stored in digital repositories that run on platforms. Repositories are developed to comply with prevailing standards and practice. Organisations and individuals develop competencies to preserve digital content for as long as needed. The proposed technology framework for technology developments of interest for digital preservation is summarised in Figure 2-2. The left column lists the technology framework categories. The right column lists examples of technology-related developments for each category. The examples could be studied individually or in combination.

To ensure that the technology framework reflects good digital preservation practice and specific community requirements, it can be checked against existing community requirements. For example, Section 1.4 introduced the five integrity features: content, fixity, reference, provenance, and context, as defined by the 1996 *Preserving Digital Information* report, and the concept of the essential properties of

[63] Section 3.6 considers the new knowledge, skills, and abilities that are needed as technological changes.
[64] The emerging preservation metadata standard, PREMIS, and preservation strategies, including normalisation using common file formats, were introduced in Section 1.3.

digital content. The integrity requirements enable the identification of technology developments that may address these five digital preservation requirements.[65]

Category	Examples
Object	file formats, storage media, metadata
Collection	relationships, metadata
Repository	workflows, tools, software, programming languages
Platform	interoperability protocols, security mechanisms, hardware
Organisation	legislation, policies, procedures, protocols
Standards	information technology, Internet, archival, description
Competencies	knowledge, skills, experience

Figure 2-2. Technology framework for digital preservation.

At the object level of the technology framework, all five of the integrity features are relevant, although the provenance and context features may be managed at the collection level. At the collection level, all five of the integrity features are also relevant, but the content, fixity, and reference may be addressed at the collection level only by referral to individual digital objects. At the repository and organisation levels, all five integrity features must be addressed with the support of the platform and standards levels.[66]

The technology framework provides a high-level organising structure for defining the scope of interest in information technology developments for digital preservation, but many information technology developments occur at a more detailed and granular level. The examples of technology developments provided in Figure 2-2 are illustrative, not exhaustive. The technology framework is not specific enough to define comprehensively the scope of interest in technology developments for digital preservation. A further level of specificity will help define a relevant scope of technology developments for digital preservation.

[65] The integrity features were introduced in Section 1.3 and are more specifically addressed in Section 2.6.
[66] The METS standard provides a structured format for addressing fixity, reference, provenance, and context integrity features. Library of Congress Network Development and MARC Standards Office, 'Metadata Encoding and Transmission Standard (METS)' Library of Congress, http://www.loc.gov/standards/mets/ (accessed 14 November 2007).

2.6 Refining the Scope of Interest

This section discusses the development of an inventory of technologies using the results of an analysis of the Open Archival Information System (OAIS) Reference Model to identify information technology developments that are of potential interest for digital preservation. The research on technology developments identified the OAIS Reference Model for this purpose because it was the first, the most comprehensive, and remains the only formal expression of the roles, functions, and entities of the digital preservation process.[67] Parsing the descriptions of the thirty-three functions in the OAIS Reference Model to identify references to technologies provided a means for developing a more detailed specification of technology developments for digital preservation. The analysis of OAIS functions defined an inventory of technologies that are potentially relevant to digital preservation.

To introduce the analysis of the OAIS functions, the seven functional groups of OAIS are briefly summarised here, highlighting the kinds of capabilities and technologies that each functional group relies upon.[68] *Ingest* receives digital content in the form of Submission Information Packages (SIPs), performs quality control checking and specified protocols for receiving digital content, supplements the metadata received with the digital content as needed, and uses the digital content and metadata to generate well-formed digital objects, or Archival Information Packages (AIPs).[69] *Archival Storage* receives the AIPs from Ingest, securely stores the AIPS, then safeguards the AIPS through continual error checking, disaster preparedness and response, and media management and replacement.[70] *Data Management* receives and manages information about the digital content over its lifecycle to support preservation and access and is responsible for administering the

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[67] References in this section are to the *Recommendation for Space Data System Standards: Reference Model for an Open Archival Information System (OAIS)*, Consultative Committee for Space Data Systems (CCSDS), CCSDS 650.0-B-1, Blue Book, January 2002. This statement reflects the status of digital preservation developments as of October 2007.
[68] Section 1.3 identified the seven functional groups of OAIS in the discussion of preservation activities.
[69] Ingest also manages migrations of file formats by regenerating AIPs with migrated formats, an important role that may not be made explicit or clear in digital preservation discussions. CCSDS, *OAIS Reference Model*, 4-5 – 4-6, 5-1 – 5-9.
[70] CCSDS, *OAIS Reference Model*, 4-6 – 4-8.

database functions for the repository.[71] *Administration* defines and applies policies, standards, and preservation strategies for the operation of the OAIS system, including the management of the platform.[72] *Preservation Planning* monitors for relevant changes in technology and the environment, and develops, tests, and recommends standards, tools, techniques, and procedures to Administration.[73] *Access* enables and controls the use of the digital content in the OAIS in the form of Dissemination Information Packages (DIPs).[74] *Common Services* provides fundamental information system support in the form of the operating system, networking controls and protocols, and system security protocols and mechanisms.[75] The analysis examined the thirty-three individual OAIS functions, but the seven OAIS functional groups provide a useful structure for summarising and discussing the results.

The analysis included an examination of the explicit relationship between the OAIS functions and the three core digital preservation activities: to identify digital content to be preserved; to take responsibility for bringing that digital content into a sustainable environment with a digital preservation regimen appropriate to the digital content; and to ensure that the digital content can be made available over time to authorised users.[76] OAIS specifically addresses the three core digital preservation activities. Identifying digital content to be preserved is defined in negotiations with the producer of the digital content, specified by Administration in submission agreements, and confirmed by Ingest upon receipt of the digital content.[77] Ensuring that the digital content is brought into a sustaining digital preservation context is enabled by Common Services and the controlled sequence provided by Ingest, Archival Storage, and Data Management with policies from Administration and recommendations for addressing the evolution of digital content from Preservation Planning.[78] Providing digital content to authorised users is coordinated by Access, managed by Administration, supported by Data

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[71] CCSDS, *OAIS Reference Model*, 4-8 – 4-10.
[72] CCSDS, *OAIS Reference Model*, 4-10 – 4-12.
[73] CCSDS, *OAIS Reference Model*, 4-12 – 4-14.
[74] CCSDS, *OAIS Reference Model*, 4-14 – 4-16.
[75] CCSDS, *OAIS Reference Model*, 4-3 – 4-5.
[76] Section 1.3 discussed the definition of digital preservation fundamentals, including these preservation activities.
[77] CCSDS, *OAIS Reference Model*, 2-9, 4-2, and 4-10.
[78] CCSDS, *OAIS Reference Model*, 4-17 – 4-18.

Management, and made possible through designs recommended by Preservation Planning.[79] This examination linked the analysis of the scope of interest in technology developments to the fundamentals of digital preservation practice.

To begin the process of refining the scope of interest in technologies for digital preservation, the research analysed the description of each function in the OAIS Reference Model document to identify references to technologies or technology capabilities, implicit and explicit, that enable the function or upon which the function would rely. This analysis of OAIS functions descriptions identified thirty-eight types of technologies and technological functionalities that enable the OAIS functions or with which it interacts.[80] An objective of the analysis was to identify technologies consistently so that the results could be used systematically to identify and track information technology developments for digital preservation.[81] The resulting technology inventory of thirty-eight capabilities and technologies are listed in Figure 2-3. Some of the technologies are higher level, e.g., artificial intelligence and systems engineering, and some are lower level, such as storage capacity. Some are complex technologies, e.g., e-commerce, and some are simple, e.g., file formats. The inventory provides a specific list of types of technologies to track for digital preservation based on the analysis of OAIS functions. The list would have to be extended and updated by the digital preservation community as technology and digital preservation requirements evolve.[82]

These are examples to illustrate the analysis of function descriptions to identify specific examples of technologies. *Receive Submission* is a function in Ingest. Receive Submission is the OAIS function that receives the digital content from a producer and issues a confirmation of receipt back to the producer (messaging mechanisms). It may involve legal transfer that requires access controls.

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[79] CCSDS, *OAIS Reference Model*, 2-9 – 2-10, 3-3, 3-5, 4-2, and 4-17.
[80] The full results of the analysis of each OAIS function are presented in Table 1 of Annex 1. The thirty-eight technologies are explained in Table 2 of Annex 1.
[81] In an actual implementation of an OAIS-based system, the functions may be performed using automated or manual means, but the inventory of technology developments presumes that the function or functionality could be automated.
[82] For example, a revision of the OAIS Reference Model is due in 2008 and that revision may affect the technology developments inventory. UKOLN, 'OAIS Five Year Review', http://www.ukoln.ac.uk/repositories/digirep/index/OAIS_five_year_review (accessed 1 June 2007).

This function may require iterative communication with the producer if there are errors in or problems with the Submission Information Package.[83] The Receive Submission function involves storage media, file formats, and metadata. It relies upon adequate storage capacity to store the digital content, at least during the check-in process; security protocols to enforce appropriate access controls; and communication capabilities to send and receive messages. *Error Checking* is the function in the Archival Storage functional group of OAIS that continually monitors and assesses stored digital content, AIPs, for indicators of degradation and potential loss.[84] Errors could indicate that storage media is failing or that the characteristics of stored file have changed since the previous check. This function relies upon the capability of hardware and software to send messages about errors, the ability of the OAIS system to store the messages in logs and to process the logs, the reliability of mechanisms to randomly check for changes in the digital content, and the ability to send and receive messages.

access controls	human computer interface	requirements analysis
artificial intelligence	integrity checking	*security*
audit controls	*logs*	*services*
authentication	*mechanisms*	*software*
checksum	messaging mechanisms	*storage capability*
confidentiality	*metadata*	*storage media*
content transfer	*monitor*	storage media management
data base development	natural language processing	*system engineering*
devices	policy enforcement	system maintenance
documentation standards	procedural protocols	*tools*
e-commerce	*prototyping*	*tracking*
file formats	query languages/syntax	*utilities*
hardware interactions	reporting	

Figure 2-3. Technology inventory of OAIS function descriptions.

Technologies in italics in Figure 2-3 were specifically cited in the descriptions of OAIS functions. For example, several function descriptions explicitly referred to storage media, i.e., Receive Submission, Quality Assurance, Receive Data, Manage Storage Hierarchy, Replace Media, Error Checking, Disaster Recovery, and Provide Data. Examples of technologies that were inferred from the function descriptions include references to:

[83] CCSDS, *OAIS Reference Model*, 4-5.
[84] CCSDS, *OAIS Reference Model*, 4-8.

- Descriptive information listed as metadata
- SIPs, AIPs, and DIPs listed as file formats and metadata to reflect the content and metadata found in all OAIS information packages
- Policies listed as policy enforcement because the references were to invoking policies
- Actions to send a confirmation receipt, send a report, receive a request listed as messaging mechanism because the underlying technology capability is sending and receiving messages

The technology inventory reflects the technologies and capabilities that were explicitly cited in or inferred from the descriptions of OAIS functions.

In addition to the technology inventory, a second outcome of the analysis of OAIS functions was a set of recurring terms that could be used as keywords to enable continual monitoring of selected technology developments. The keyword list, like the inventory of technologies, could be extended and maintained by the digital preservation community as technology evolves. Figure 2-4 presents examples of keywords for each OAIS functional group. A similar list could be developed and maintained for each OAIS function and for each item on the technology inventory for continual monitoring.

OAIS functional group	**Keywords**
Common Services	Security, networks, authentication, operating system
Ingest	Acquisition, selection, quality control, validation
Archival Storage	Persistent storage, storage media, file formats, migration
Data Management	Metadata, database, access control
Administration	Audit, policies, procedures
Preservation Planning	Preservation strategies, longevity, persistence, standards
Access	Use, usability, user expectations, rights management

Figure 2-4 Keywords for relevant technology developments.

Analysing the OAIS functions demonstrates an approach for refining the scope of interest in technology developments for digital preservation. Ongoing tracking of technology developments in all of the areas identified by the technology inventory would produce a large number of technology developments that might have potential implications for digital preservation.[85] Developing a means for prioritising the resulting list of potentially relevant technology developments would enable the digital preservation community to identify, assess, and respond to the most significant technology developments.

2.7 Prioritising Technology Developments

The inventory of technologies for digital preservation defined a scope of interest that includes more than file formats and storage media but less than the totality of information technology developments. All of the technology types on the inventory are of potential interest for digital preservation because each plays a role of some kind in preserving digital content. To limit the possible scope of interest to technologies that are most significant for digital preservation, the next step in the research was to develop and apply a set of criteria to prioritise technology developments for digital preservation. One aim of the research was to ensure that the process of developing and applying the criteria was as objective and consistent as possible.

The five integrity features defined by the authors of the *Preserving Digital Information* report (content, fixity, reference, provenance, and context; see Section 2.5 and 2.6) provided a starting point for developing criteria to prioritise technology developments for digital preservation.[86] The OAIS Reference Model reflects the integrity features in its definition of a digital object.[87] OAIS refers to content as the Content Data Object (the content itself) and its Representation Information (the technical information necessary to display and use digital content). In OAIS, Preservation Description Information explicitly includes four of the integrity criteria, provenance, context, reference, and fixity.[88]

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[85] Technology assessment as a type of technology response was introduced in Section 1.7 and is discussed in Section 3.3. The technology assessment referred to here would be similar to the technology assessment completed as part of the object-based technology response example discussed in Section 5.6.
[86] *Preserving Digital Information*, 12-19.
[87] OAIS refers to a digital object as an information package. Within OAIS, an information package has two major components, content information and preservation description information. CCSDS, *OAIS Reference Model*, 2-5 - 2-6.
[88] CCSDS, *OAIS Reference Model*, 2-6.

The analysis of OAIS functions that produced the technologies inventory also highlighted requirements of OAIS functions. These requirements in combination with the five integrity features contributed to the definition of five priority criteria for technology developments for digital preservation: *contact*, *interaction, opportunity*, *risk management*, and *automation*. These priority criteria were used in this second analysis of OAIS functions that builds on the results of the first analysis. The rationale for each priority criterion is discussed in the following paragraphs.

The *contact* criterion builds on further analysis of the roles of the OAIS functions as direct, enabling, or indirect. A function that plays a *direct* role requires contact with digital content. Eight OAIS functions were determined to have direct roles in digital preservation.[89] A function that plays an *enabling* role provides an important digital preservation function without having direct contact with digital content. Sixteen OAIS functions were determined to have enabling roles.[90] A function that plays an *indirect* role has a less immediate part in the preservation of the digital content. Nine OAIS functions were determined to have an indirect role in digital preservation.[91] To meet the contact criterion, the OAIS function involves or requires direct contact with the digital content.

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[89] The full results of this step in the analysis are provided in Section 1 of Annex 1.The OAIS Functional Group to which the OAIS function belongs is indicated in parentheses after the name of the OAIS function. The eight functions identified as having a direct role in digital preservation were: Audit Submission *(Administration)*, Coordinate Updates *(Ingest)*, Generate AIP *(Ingest)*, Quality Assurance *(Ingest)*, Receive Data *(Archival Storage)*, Receive Submission *(Ingest)*, Replace Media *(Archival Storage)*, and Security services *(Common Services).*

[90] The sixteen functions identified as having an enabling role in digital preservation were: Administer Database *(Data Management),* Archival Information Update *(Administration)*, Develop Packaging Designs and Migration Plans *(Preservation Planning)*, Develop Preservation Strategies and Standards *(Preservation Planning)*, Disaster Recovery *(Archival Storage)*, Error Checking *(Archival Storage)*, Establish Standards and Policies *(Administration),* Generate Descriptive Information *(Ingest)*, Manage Storage Hierarchy *(Archival Storage)*, Manage System Configuration *(Administration),* Monitor Designated Community *(Preservation Planning)*, Monitor Technology *(Preservation Planning),* Negotiate Submission Agreement *(Administration),* Network services *(Common Services), Operating System services (Common Services),* and Physical Access Control *(Administration).*

[91] The nine functions identified as having an indirect role in digital preservation were: Activate Requests *(Administration)*, Coordinate Access Activities *(Access)*, Customer Service *(Administration)*, Deliver Response *(Access)*, Generate DIP *(Access)*, Generate Report *(Data Management)*, Perform Queries *(Data Management)*, Provide Data *(Archival Storage)*, and Receive Database Updates *(Data Management).*

For this analysis, contact by the OAIS function with the digital content may be constant from the moment the SIP is received by the digital archive, may occur periodically at specific points in the lifecycle of the digital content, or may occur at a single point in the lifecycle that is defined by the OAIS functions. If the OAIS function was identified as having some kind of contact, the contact criterion was flagged during the analysis. OAIS functions that require direct interaction with digital content, represented by the AIP, participate in establishing and ensuring the chain of custody for the digital content.[92] Contact pertains to the fixity, reference, and provenance integrity features because contact should not adversely affect fixity, identifiers should enable and be unbroken by contact, and contacts with the digital content must be recorded as provenance events. To ensure integrity, contact with the digital contact must be known, documented, and controlled.

To meet the *interaction* criterion the OAIS function must respond to or be involved in, not just be made aware of, changes in digital content.[93] Interaction results in some kind of change to or transformation of the digital content. Interaction is an extension and specialisation of contact.[94] Interaction may pertain to all five of the integrity features because:

- The content may be affected by the interaction
- Fixity must be ensured during the interaction
- References that identify and connect digital objects must remain intact during transformations
- Provenance must be preserved intact during transformations
- Linkages between objects must be unbroken by and updated as needed after transformations

[92] In the context of digital preservation, the chain of custody is a record of everything that happens to or is done to the digital content, ideally throughout the lifecycle of the digital content or at minimum from the point at which the digital content is received by a digital preservation programme. The concept of chain of custody and the integrity features were introduced in Section 1.3.
[93] For example, the *Error Checking* function would detect and respond to potential problems with the storage media on which an AIP is stored, possibly by moving the affected AIP to another storage media. CCSDS, *OAIS Reference Model*, 4-8.
[94] The definition of this criterion began with a consideration of the distinctions between conveying or carrying a message, reading a message, and responding to a message. These are common characteristics identified in the descriptions of OAIS functions that turned up repeatedly in the analysis of OAIS functions discussed in Section 2.6.

Provenance events include transformations that occur during as well as prior to archival custody.

The *opportunity* criterion requires that the OAIS function must have the potential to contribute to the effectiveness of digital preservation strategies by exploiting opportunities offered by technology developments that enhance or enable the capability of an OAIS system to process, store, update, or otherwise manage digital content. Reflecting on the innovation cycle discussed earlier in this chapter, any technology or capability might meet the opportunity criterion. Functions that identify the need for protocols, techniques, tools, utilities, mechanisms, and services are examples of technologies and capabilities with great opportunity potential because these will have to evolve as technology evolves to remain useful. Opportunity might enable and should not inhibit any of the integrity features.

To meet the *risk management* criterion, the OAIS function participates in the avoidance of potential risks that would affect the integrity, longevity, or authenticity of the digital content.[95] Risk management is most relevant to the fixity integrity feature, but risk management would detect changes in content and respond, utilise reference identifiers to detect and respond to potential risks, ensure that the provenance of digital content is documented and protected, and assess the context of digital content to detect risks or threats.

To meet the *automation* criterion, the OAIS function must have the potential to perform more effectively for digital preservation if the process enabling the function were automated. This criterion is particularly relevant when automation would ensure or enhance the integrity, authenticity, or provenance of a digital object. Automation is also relevant when accuracy or consistency is required and automation would remove or reduce the potential for human error. Automation might enable any of the integrity features.

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[95] Examples relevant to risk management that were identified during the analysis include OAIS functions that participate in the security, e.g., Security Services within Common Services, or protection of the digital content, e.g., Quality Assurance in Ingest or Replace Media, Disaster Recovery, and Error Checking in Archival Storage.

These five criteria address digital preservation requirements for ensuring that the chain of custody for digital content is intact and auditable from the point of submission throughout the lifecycle of the digital content and for enabling a comprehensive and consistent process for preserving digital content.[96] The analysis applied the priority criteria to assign a score to each OAIS function and produced a cumulative score for each OAIS function totalling the five individual scores. The scores were assigned according to the following three rules. If the analysis of the OAIS function determined that the criterion definition applied to the function, the function received 10 points. If the criterion definition partially or sometimes applied to the function, the function received 5 points. If the criterion definition did not apply to the function, the function received 0 points. The highest possible score is 50, if all five criteria fully applied to the function, and the lowest possible score is 0. Figure 2-5 presents a summary of the scores assigned for each OAIS functional group.[97] The number in parentheses after the OAIS functional group indicates the total number of OAIS functions the functional group contains, e.g., the Ingest functional group of OAIS consists of five functions. As an example, four of the five Ingest functions received a score of 50 and one Ingest function received a lower score between 35 and 20. The results of this process represent a first step towards prioritising technology developments for digital preservation.

	Score Ranges				
OAIS functional group	**50**	**45-40**	**35-20**	**15-10**	**0**
Common Services (3)[98]	1	0	2	0	0
Ingest (5)	4	0	1	0	0
Archival Storage (6)	1	3	2	0	0
Data Management (4)	0	0	2	2	0
Administration (8)	1	1	4	1	1
Preservation Planning (4)	0	3	1	0	0
Access (3)	0	0	1	2	0

Figure 2-5. Summary of priority scores for OAIS functions.

[96] The concept of chain of custody was introduced in Section 1.3.
[97] Section 3 of Annex 1 contains the score sheet for this analysis with the score assigned for each criterion to each OAIS function. Section 4 of Annex 1 presents the OAIS functions in order by total score assigned.
[98] Common Services consists of Operating System services, Network services, and Security services. These service areas are described in more general terms in the OAIS Reference Model document using examples and suggested services for each. In practice, each of the service areas might contain multiple functions, but for the purposes of this discussion Common Services is considered to have three functions, one for each service area. CCSDS, OAIS reference Model, 4-3 – 4-5.

This ranking process assigned high scores to four of five functions in Ingest and one each in the Archival Storage, Administration, and Common Services functional groups. These are some observations about the ranking: [99]

- The results confirm that Ingest plays an interactive and ongoing role with digital content. Ingest includes perhaps the most crucial digital preservation function: Generate AIP. If that function works improperly, preserving the digital content will be extremely difficult or impossible because the resulting AIPS might be incomplete or malformed.
- Archival Storage plays an essential role in preserving digital content including responsibility for core aspects of digital preservation, e.g., storage management and disaster recovery. In addition to one Archival Storage function that received the highest score, three more Archival Storage functions received a score of 45, the next highest possible score.
- Administration functions play a formative and normative role in digital preservation, but a role that generally requires no direct interaction with digital content, with the exception of the Audit Submission function, which may take the form of an examination of all or a selected portion of the digital content in the OAIS.
- Common Services play an important and ongoing role in digital preservation through the provision of essential services, e.g. the operating system, network services, and security services. With the exception of Security Services, Common Services enable direct interactions with digital content, but do not require direct interaction with digital content.
- Preservation Planning is the functional group that scored next highest in the ranking. Like Administration, Preservation Planning plays a formative role, but performs its functions in a test mode not a production mode, e.g., working with test versions rather than actual digital content. Preservation Planning functions work with test copies of digital content and require no direct interaction with actual digital content.
- Access functions benefit from the other OAIS functions and play an indirect role in digital preservation. Providing access to digital content serves as an

[99] The full results of the ranking process are presented in Sections 3 and 4 of Annex 1.

important audit on the effectiveness of the other functions because if access to digital content is not possible or is not adequate, then digital preservation has failed to meet its objectives.

These results allow technology developments to be prioritised based on the potential impact of implementing the technologies for digital preservation.

The results of applying the priority criteria align very closely with the results of assigning roles to OAIS functions, as shown in Figure 2-6. OAIS functions that were identified as having a direct role in digital preservation received high scores. OAIS functions identified as having enabling roles received medium to high scores. OAIS functions identified as having indirect roles received lower scores.[100] These results represent a second step towards prioritising technology developments for digital preservation.

OAIS function (OAIS functional group)	**Role**	**Score**
Audit Submission *(Administration)*	Direct	50
Coordinate Updates *(Ingest)*	Direct	50
Generate AIP *(Ingest)*	Direct	50
Quality Assurance *(Ingest)*	Direct	50
Receive Data *(Archival Storage)*	Direct	50
Receive Submission *(Ingest)*	Direct	50
Security services *(Common Services)*	Direct	50
Replace Media *(Archival Storage)*	Direct	45
Disaster Recovery *(Archival Storage)*	Enabling	45
Error Checking *(Archival Storage)*	Enabling	45
Develop Packaging Designs… *(Preservation Planning)*	Enabling	40
Develop Preservation Strategies … *(Preservation Planning)*	Enabling	40
Establish Standards and Policies *(Administration)*	Enabling	40
Monitor Technology *(Preservation Planning)*	Enabling	40
Archival Information Update *(Administration)*	Enabling	35
Manage Storage Hierarchy *(Archival Storage)*	Enabling	35
Manage System Configuration *(Administration)*	Enabling	35
Monitor Designated Community *(Preservation Planning)*	Enabling	35
Negotiate Submission Agreement *(Administration)*	Enabling	35
Network services *(Common Services)*	Enabling	35
Administer Database *(Data Management)*	Enabling	30
Generate Descriptive Information *(Ingest)*	Enabling	30
Operating System services (Common Services)	Enabling	30

[100] The one anomaly between the two approaches was Generate DIP, an access function with an indirect role that received a high score of 35 out of a possible 50 points. The specific scores explain the anomaly because the Generate DIP correctly received 10 points each for opportunity and automation.

OAIS function (OAIS functional group)	Role	Score
Physical Access Control *(Administration)*	Enabling	20
Generate DIP *(Access)*	Indirect	35
Provide Data *(Archival Storage)*	Indirect	20
Receive Database Updates *(Data Management)*	Indirect	20
Coordinate Access Activities *(Access)*	Indirect	15
Activate Requests *(Administration)*	Indirect	10
Deliver Response *(Access)*	Indirect	10
Generate Report *(Data Management)*	Indirect	10
Perform Queries *(Data Management)*	Indirect	5
Customer Service *(Administration)*	Indirect	0

Figure 2-6. Combined results from priority criteria and roles.

The scores for the OAIS functions can then be matched to the technology inventory to generate a prioritised list of technology developments for digital preservation. Many of the technologies are associated with more than one OAIS function. This recurrence allows the technology priorities to be refined. Using the highest score assigned to a technology development based on any OAIS function with which the technology is associated identified larger clusters of potentially relevant technology developments because a number of technology developments would have the same top score. Using the cumulative score assigned to a technology development based on all the OAIS functions with which the technology is associated produced a refined list of priorities that distinguishes between more and less relevant technology developments. Many references to a lower scoring technology would not be as significant as fewer references to a higher scoring – and therefore, more significant – technology. This led to the addition of the frequency of references to the technology. Figure 2-7 presents these results for the high score and cumulative score for each of the thirty-eight technologies with the results sorted in decreasing order by cumulative score. This is the final step in demonstrating how technology developments could be prioritised for digital preservation. This scoring process could be integrated into a monitoring program to provide users of the information about technology developments with a means to determine the relative significance of technology developments that are detected and tracked.

Technology	High score	Cumulative score	Frequency
messaging mechanisms	50	915	28
procedural protocols	50	840	25
reporting	50	535	17
metadata	50	440	13

Technology	High score	Cumulative score	Frequency
content transfer	50	355	9
file formats	50	305	7
storage media	50	305	7
access controls	50	260	7
policy enforcement	50	255	7
mechanisms	50	210	6
artificial intelligence	50	205	5
natural language processing	50	205	6
integrity checking	50	195	5
tools	50	195	5
tracking	40	185	8
human computer interface	50	165	4
security	50	165	4
services	50	160	4
requirements analysis	40	150	4
logs	50	125	3
utilities	50	125	3
monitor	40	110	3
devices	50	100	2
documentation standards	50	90	2
audit controls	50	85	2
authentication	50	85	2
confidentiality	50	85	2
prototyping	40	80	2
hardware interactions	35	65	2
query languages/syntax	35	60	4
checksum	50	50	1
storage capability	50	50	1
storage media management	35	35	1
system engineering	35	35	1
system maintenance	35	35	1
data base development	30	30	1
software	30	30	1
e-commerce	0	0	1

Figure 2-7. Comparative scores for the technology inventory.

These sequential steps suggest how priorities could be established for technology developments to adjust the scope of interest for digital preservation using defined criteria. The purpose of this process was to evaluate the potential significance for digital preservation of technology developments using the OAIS Reference Model as the most comprehensive digital preservation standard. The results of applying established criteria could also be used to identify technology developments as candidates for digital preservation technology assessments. The approach is intended to suggest a means for setting priorities to focus the results of tracking technology developments for digital preservation, rather than to prescribe specifically how priorities are set. It should be possible to use the results in a 'top-down' or 'bottom-up' manner. If the starting point is an interest in a particular category of the technology framework, it is possible to navigate down to specific technologies and developments that pertain to that category. If the starting point is the detection of a technology development that might be of interest for digital preservation, it is possible to navigate up by matching the technology developments to a technology on the inventory and then up to the categories of the technology framework. [101] The combination of the technology framework, technology inventory, and prioritisation process provides a comprehensive means to define and refine the scope of interest in technology developments for digital preservation.

2.8 Information Sources for Technology Developments

Once the technology developments to track are identified, the next challenge is to gather requisite information to understand and respond to those technology developments. The sources of information about potentially significant technology developments are varied and voluminous. In addition to the large quantity of information about technology, relevant general and specific sources on technology are located in many domains.[102] This section addresses the types, characteristics, and uses of sources of information about technology developments for enabling technology responsiveness for digital preservation. Information about the types and characteristics of technology sources was an integral part of completing the research, the accumulation of which enabled this analysis. The high-level quantitative observations presented in this section reflect the results of a survey of technology-related publication entries in *Ulrich's International Periodicals*

[101] This is an example of how that navigation would work. The technology inventory primarily pertains to the repository and platform categories of the framework. There is an implicit relationship to the object category of the framework through technologies that pertain to the creation and management of the Archival Information Package (AIP), There is an implicit relationship to the collection category through the development and management of the Archival Information Collection (AIC) that defines aggregations of digital objects as represented by AIPs. There is an explicit or implicit relationship to standards informing the development of technologies on the inventory, i.e. sometimes specific standards are referenced. The Administration functional group and the Management role in OAIS relate to the Organisation category in the framework, with the additional reference of the TDR document. The need to develop appropriate competencies pertains to all of the categories. CCSDS, *OAIS Reference Model*, 4-42 – 4-43. OCLC and RLG, *Trusted Digital Repositories*.

[102] Section 2.2 discussed the literature about technology and technological change across a range of domains.

Directory between 1980 and 2005. The more specific qualitative observations discussed in this section resulted from an analysis of information sources that were identified during the investigation of technology developments discussed in this chapter. The evaluation of technology responses is discussed in Chapter 3 and the completion of the technology response example discussed in Chapter 5.

There is a notable gap between the amount of information available about technology developments across domains and the presence of citations for technical literature in the literature of the digital preservation community.[103] The research included a survey of periodicals on information technology topics using *Ulrich's International Periodicals Directory* to understand the extent and growth of information about technology.[104] The survey identified technology and computer-related periodicals in the 1980, 1985, 1990, 1995, 2000, and 2005 editions of Ulrich's. The 1980 edition of Ulrich's contained 385 subject classifications, only one of which explicitly referred to computers, *Computer Technology and Applications*. The survey documented a major growth in technology-related periodicals beginning in 1985 that parallels the growth of desktop computing. The three-fold growth in technology-related periodicals from 1980 to 2005 is significant as the subject classifications in the directory document emerging technologies. [105] Figure 2-8 summarises the survey of technology-related periodicals in Ulrich's. The results provide a high-level, quantitative indicator of the growth of information about technology developments.

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[103] The lack of citations for technical literature was discussed in the literature review in Section 1.6.
[104] The survey of Ulrich's noted the number of periodicals, the number of new periodicals (periodicals that started since the previous reviewed edition), and the topics covered by the periodicals for each technology-related classification.
[105] For example, the total number of periodicals increased from 62,000 to 186,000. There is an unexplained drop in the number of entries in many categories in the 2000 edition. The growth in CD-ROM and on-line publications has been exponential, rising from 172 in 1990 to 6,600 in 2005. Web sites made a huge impact by the 2000 edition, the first edition surveyed that included URLs for publications. The number of URLs almost doubled in five years, increasing from 52,000 in 2000 to 97,000 in 2005. Changes in the technology for the dissemination of information are reflected in the shift of the content of periodicals from microform to CD-ROM to Internet resources. The sub-classification for the Internet was not present in 1995, but had been added by the 2000 edition. Computer-related subjects included: artificial intelligence, assisted instruction, automation, circuits, cybernetics, database management, electronic data processing, hardware, information science, information theory, machine theory, microcomputers, minicomputers, personal computers, robotics, software, theory of computing, and word processing. Sub-categories within computers included computer architecture, engineering, games, graphics, music, networks, programming, security, simulation, and systems.

The analysis of information sources for this research identified four major categories of sources: textbooks, technical journals and articles, research reports, and news items.[106] Each category has characteristics that could play a role in developing an understanding of the implications of technology developments and in the completion of technology assessments for digital preservation.[107] The discussion of each category characterises the information sources in the category, provides examples from the research, and suggests the utility of the category for tracking and understanding technology developments.

Classification/Sub-classification	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**
Entries for the *Computers* Classification	538	251	482	474	520	840
Entries for *Technology: Comprehensive Works*[108]	383	459	797	871	886	1,190
Entries for Computer Sub-classifications[109]	0	425	666	1005	1210	1406
Total entries	921	1135	1945	2350	2616	3436

Figure 2-8. Summary results from the survey of periodicals.

Although the format and delivery mechanisms are changing, textbooks continue to play an essential role in education.[110] Textbooks present an overview of a specific topic or a broad area, discuss fundamental principles and topics, and

[106] There are supplementary sources on technology that would be included in a full implementation of technology responsiveness, but the four studied represent a critical mass of information for understanding technology developments. For example, one author proposed seven categories of indicators for technology developments of interest for software engineering: market performance reports, reports on science and technology research and development, patents and other science and technology outputs, academic degrees awarded and other measures for the supply and demand of relevant expertise, reports on expenditures and funding on research and developments, updates on standards and regulations, and definitions of best practice that reflect the state of the art. Cowen, Robert David et al., 'Software Engineering Technology Watch,' *IEEE Software* (July/August 2002), 124. These categories overlap with the major sources discussed in this section and provide potential additional examples of sources of information on technology developments for digital preservation.
[107] Section 4.12 discusses the accumulation of content for the technology response model and Section 6.4 considers the logistics of accumulating sources as an implementation consideration.
[108] The Technology: Comprehensive Works classification includes all technology-related entries, not only information technology entries.
[109] Beginning in the 1985 edition, an increasing number of subject classifications had a sub-classification called *Computer Applications*. Approximately 60 classifications included this sub-classification between 1985 and 2005. A number of these sub-classifications contained no entries or very few entries. The classifications that had the most entries for Computer Applications were Education, Communications, Library and Information Sciences, Mathematics, Medical Sciences, Publishing and Book Trade, Banking and Finance: Computer Applications, Law, Linguistics, and Science: Comprehensive Works.
[110] For example, Cecilia Braslavsky, ed. with Katya Halil, Textbooks and Quality Learning for All: Some Lessons Learned from International Experiences (Paris: United Nations Educational, Scientific and Cultural Organization (UNESCO), 2006); and Oxford University Press, 'Higher Education Textbooks', http://www.oup.co.uk/oxfordtextbooks/ (accessed 11 November 2007).

provide an introduction for further study.[111] Textbooks contribute to the identification of emerging and dominant types of technologies; introduce potentially complex topics in an understandable and approachable manner; identify additional sources and advanced topics; and provide context and background information for discussions. Textbooks proved most helpful in the early stages of the exploration and in establishing a basic understanding of technology topics and specific issues that emerged during the technology assessment, for example.[112]

Considering the potential role of information sources in monitoring technology developments for digital preservation, textbooks chart the emergence and diffusion of technology developments in hindsight and capture the evolution of technology developments from emergence to acceptance to obsolescence. The content of textbooks to provide a baseline of information for students reflects mainstream developments rather than the most advanced and emergent, although seminal works are cited and projections about the future are often included. This means that textbooks typically provide information about technology developments in the innovation and diffusion stages, and they are not the best source of information about inventions, except historically. Textbooks are valuable for exploring mainstream developments and looking ahead in the short-term for emerging developments. Textbooks provide a starting point that leads to deeper and more advanced sources.

While textbooks have many characteristics in common with each other, journals and articles are much more varied. Depending on the objectives of the

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[111] For example, the technology response example research repeatedly encountered textbooks on database systems, the most common label for broad treatments of topics pertaining to information systems. Two examples illustrate important characteristics of textbooks. A 1999 textbook entitled *Database Systems: A Practical Approach to Design, Implementation, and Management* includes object-based system issues in discussing current trends and identifies Web-related database issues as a future trend. Thomas M. Connolly, Carolyn E. Begg, and Anne D. Strachan. *Database Systems: A Practical Approach to Design, Implementation, and Management*, 2nd ed, International Computer Science Series (Wokingham, England: Addison-Wesley, 1998), xix-xx. The eighth edition of *Modern Database Management* released in 2007 identified object-based systems as an advanced database topic. Jeffrey A. Hoffer, Mary Prescott, and Fred McFadden, Modern Database Management, 8th ed. (Upper Saddle River, NJ: Prentice Hall, 2007).

[112] In completing the technology response example, textbooks were informative sources for establishing the information technology landscape, and specialised textbooks provided explanations of core topics, e.g., database development and object-oriented concepts. For example, Connolly, Begg, and Strachan, *Database Systems*; and Ivar Jacobson, *Object-Oriented Software Engineering: A Use Case Driven Approach* (Wokingham: Addison-Wesley, 1992).

journal, the nature of the topics, and the perspective of the authors, articles may be general or specific, discuss developments in conceptual or concrete terms, present the information in an introductory or advanced manner, and provide a broad or deep analysis of a topic. In technical articles on technology topics, mathematics and abstruse terminology can be daunting.

Common patterns in the presentation of the information proved beneficial during the research in understanding the relevance of the topic for a technology assessment for digital preservation, for following the basic arguments presented in articles, and for extracting essential information from the article. For example, most journals require an abstract that succinctly describes the purpose and essence of the article and most articles expand on the abstract in the introduction and synthesise the arguments in the conclusion. Technical journals provide authoritative, peer-reviewed sources, enable systematic and chronological searching, and present differing perspectives on core topics under discussion in a domain. Technical articles provide more extensive discussions and explanations of topics, explore alternatives for developing and implementing technology developments, discuss challenges and opportunities, and propose solutions for potential barriers in the emergence of a technology development. Technical journals and articles proved most helpful in filling in gaps about specific topics and deepening an understanding of complex topics.[113]

In terms of monitoring technology developments for digital preservation, technical journals and articles may identify key trends, explore core issues, and address major obstacles in the innovation or diffusion of a technology development. The publication process contributes to the quality of technical articles, but also adds to the time required to distribute the information contained in the articles. The rise in pre-print versions of articles offsets this concern about the currency of the information, but the content of technical articles published in technical journals may not reflect the most current information about technology developments. Technical

[113] In completing the technology response example, technical journals were helpful in tracing trends for defining the technology landscape for the technology assessment. Technical articles also contributed to a general understanding of information systems and a specific understanding of object-based systems. Technical articles identified developmental and implementation issues that needed to be considered in the assessment. Results for the technology assessment portion of the technology response example are discussed in Section 5.6.

articles address technology developments in the late invention or early innovation stage onward because innovators do not want to reveal information about developments too early in the invention stage, either because the invention might not succeed or to avoid competition.

Research reports, including research project Web sites, technical reports, and white papers form a third category of information sources about technology developments. The content in this category varies greatly from project to project.[114] Some research projects provide information systematically and comprehensively; other research projects are more sparse. Often this information is provided on a project Web site or a Web blog or other online means for sharing information. It can be difficult to find final research reports and outcomes. Reports by vendors and consultants complicate the use of information in this category because commercial claims and motivations may be presented as research and there are typically costs associated with acquiring this kind of information. Research projects often address emerging developments and reflect trends in technology developments. This kind of information may represent the most current information about an emerging technology development or some aspect of it. Without the peer-review process of technical journals, it can be more difficult to identify authoritative or valid sources of information about research. Conference presentations and proceedings cited by the research projects can assist in addressing this aspect of using research reports as an information source about technology developments.

Research reports often address the invention stage of technology developments, but these reports may also address the innovation stage of technology developments.[115] Research reports may identify features and limitations of technology developments that are informative for technology assessment purposes. Research reports tend to be less likely to address the diffusion stage, which is the innovation stage when commerce and industry take over from research,

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[114] For example, research project reports may provide the project proposal that describes what the project is intended to accomplish; status reports that plot the progress and identify changes in course; technical reports and research reports of differing lengths and presented with varying levels of formality; results and observations from the research; relevant and recommended sources of information about the topics or the research; and final reports about the outcomes.

[115] In completing the technology response example (see Chapter 5), research projects contributed to the identification of trends in information systems generally and object-based systems specifically.

although barriers to diffusion might become the topic for a research project. In terms of monitoring technology developments for digital preservation, research reports can trace the emergence of developments and the shift of developments into mainstream focus. Trends in the priorities of research funding agencies and foundations may also reflect the emergence or significance of technology developments.

The final category of information sources about technology developments is news sources, including announcements from vendors, press releases about new developments or mergers, newspaper articles, Web blogs that track information technology generally or specific aspects of it, and television or radio programmes. Information in this category often proved to be brief and not very informative, although this type of information source can identify early indicators of developments and of shifts from one development stage to another, e.g., a technology development moving from the invention to innovation stage or the innovation stage to the diffusion stage. Press releases and announcements may be more informative, depending on the stage of development and the objective of the news, to be informative, to be provocative, or to stake a claim. Online news sources are increasingly available and, as with research reports, verifying or evaluating the source needs to be considered in using the information. News sources proved useful in tracing milestones and key features in the development of past or current technologies.[116] News sources range from formal to informal providers, e.g., technology-related columns in newspapers or notes in Web blogs; from general to specific topics, e.g., industry trends or product announcements; and from recent to future events, e.g., increases in the sale of a type of software or forthcoming product releases. In tracking technology developments for digital preservation, this kind of information might identify a technology development that warrants a technology assessment.

The discussion of these categories suggests the role that different types of information sources about technology might play in developing an understanding of a technology development and in completing a technology assessment. The

[116] In completing the object-based technology response example, news sources contributed to the identification of evaluation factors for technology assessments.

characteristics of each source will make it relevant at particular stages in responding to a technology development or during the technology assessment process.

2.9 Conclusion

Responding to technological change requires a comprehensive understanding of its nature and characteristics. The exploration noted that technological change is change resulting from technology. The exploration identified five characteristics of technology – technology as objects, knowledge, activities, process, and system, illustrating the complexity of the term technology and the many ways in which it can be understood. Technological change is the accumulation of technology developments and the resulting impact of the sum of technology developments.

Responding to technological change, a complex phenomenon, will require a means to identify the components of technological change – technology developments – then to formulate and measure responses. Having defined the core concepts pertaining to technological change, the research addressed the means to define an appropriate scope of interest in technology developments. The research outcomes include the technology framework for digital preservation, the technology inventory identifying technologies of potential concern for digital preservation with sample keywords to monitor technology developments for digital preservation, priority criteria for identifying technology developments with potential significance for digital preservation, and an analysis of the value of information sources about technology developments for digital preservation purposes.

The technology framework for digital preservation includes the categories of the object, collection, repository, platform, organisation, standards, and competencies. The technology framework broadens the scope from a focus on technology developments that is focused on file formats and related software and storage media. The technology inventory identified a more granular list of relevant technology developments that may be mapped to the categories of the technology framework and reflect existing standards and good practice for digital preservation. The technology inventory provides a means to monitor technology developments more specifically and allows the scope of interest in technology developments for digital preservation to include only relevant technology developments. The priority criteria provide a means to focus on the most significant technology developments.

These observations resulted from the investigation of technological change and informed the development of the technology response model for digital preservation. A significant observation from this exploration is that technological change might refer to a single technology development, a related set of technology developments, or the broad landscape of cumulative change that results from technology. For technology responsiveness by a community to be measurable, it will be necessary to specify the scope of technological change within the broad possible landscape of technological change. Awareness of technological change is an ongoing and cumulative process as technology evolves. An assessment of one or more technology developments occurs at a point in time for a specific iteration of a technology development, informed by available information at that point in time. Therefore, one result of a technology assessment might be that a future assessment is needed after specific technology developments have occurred or matured.

The primary objective of this investigation was to broaden the understanding of technological change to enable the development of a response by the digital preservation community. Together, the technology framework, technology inventory, and priority criteria define boundaries for a scope of interest in technology developments for digital preservation that is not too broad and not too narrow, and the application of these techniques provides the means for the scope to be refined as technology evolves. The construction of the technology response model for digital preservation, discussed in Chapter 4, incorporated these results.

Chapter 3. Adapting Technology Responses for Digital Preservation

3.1 Introduction

This chapter evaluates responses to technology that have been developed to assess the applicability and feasibility of these responses for digital preservation. The review of existing responses to technology by the digital preservation community, discussed in Section 1.5, showed that most of the digital preservation responses have been limited to avoiding obsolescence of known file formats.[1] The technology responses developed outside the digital preservation community have received no substantive attention in the literature of the digital preservation community, with exceptions that are noted in the discussion.

The analysis of technology-related literature for this research identified four distinct types of technology responses: technology forecasting, technology assessment, technology transfer, and technology monitoring.[2] This chapter discusses each of these technology response types, considers the more general issue of the human response to technology, and concludes by assessing the potential of each technology response type for digital preservation and the cumulative value of existing technology responses for developing a technology responsiveness approach for the digital preservation community.

3.2 Technology Forecasting

Technology forecasting is “the systematic process of describing the emergence, performance, features, or impacts of a technology at some time in the future”.[3] This technique is covered by extensive literature and theory. Technology forecasts are often used to identify potential profits or benefits for an industry or an organisation. Short-term forecasts tend to identify potential enhancements to

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[1] Section 1.5 acknowledged the extent and importance of these developments that were documented through October 2007.

[2] The results of technology monitoring are often presented in a technology watch service. Section 1.5 introduced technology watch examples within the digital preservation community.

[3] Technology Futures Analysis Methods Working Group, ‘Technology Futures Analysis: Towards Integration of the Field and New Methods’, *Technology Forecasting and Social Change* 71 (2004): 289.

existing technologies; long-term forecasts are more likely to identify trends in technology developments.[4] Technology forecasts are often conducted by consultants, so forecasting results are generally treated as internal documents that are not widely available.[5] At the national level, forecasts tend to focus on large issues, such as the budget or the impact of industry on the climate.[6]

Technology forecasting applies a set of techniques for predicting the types and characteristics of technologies that will be developed. The techniques work well when applied to three situations: 1.) projecting the rate of adoption of a new process or product; 2.) predicting developments and discoveries in a specific domain or area; and 3.) characterising the nature and patterns of changes based on technology developments.[7] The primary purpose of technology forecasting is to enable businesses to make good decisions about investments in technology research and development.[8] Technology forecasting identifies opportunities and threats to an organisation or industry based on the projected market penetration and other indicators of technology developments.[9] Jones and Twiss suggest "the thesis is that when active minds are applied to the best available data in a structured and systematic way they will have a clearer vision of the future than they would have by intuition alone".[10]

Beginning in the early 1960s as the use of computers spread, technology forecasting emerged in economics and was taken on by technologists and engineers, all of whom wanted to identify significant trends and opportunities to utilise, adapt

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[4] Jones and Twiss, *Forecasting Technology*, 2.
[5] The survey of technology watch examples discussed in Section 3.5 identified sample technology forecasts, usually at a high-level, which may be used by consultants to attract clients. An example is the forecasts provided by the Battelle organisation. Battelle, 'High Tech Haven: Forecast Predicts the Top Ten Innovations in Home Comfort and Convenience in 2012', News Release, 9 July 2002, http://www.battelle.org/news/02/07-09-02Healthy.stm (accessed 10 May 2008).
[6] The review of technology response types suggests that governmental interest in technology developments is more likely to take the form of technology assessment and technology transfer. One exception is the Foresight Project of the Office of Science and Technology , which was established in 1993 to develop strategies based on monitoring and forecasts. Fore*sight* Programme, http://www.foresight.gov.uk/ (accessed 10 May 2008).
[7] Spyros Makridakis, and Steven C. Wheelwright, *Forecasting Methods for Management*, 5th ed. (London: John Wiley & Sons, 1989), 319.
[8] Bauer, et al, *Second Order Consequences*, 3.
[9] Jones and Twiss, *Forecasting Technology*, 87.
[10] Jones and Twiss, *Forecasting Technology*, 2, 10.

and extend technology developments.[11] Its emergence coincided with an increase in management education and quantitative methods.[12] In the early applications of forecasting techniques, the complex interactions between layers of technology developments were not extensively discussed or studied.[13] The inaccuracies of predicting the future of technology developments led to a decreased use of technology forecasting by the 1970s.[14] To offset these early failures, later authors specified situations appropriate to the use of technology forecasting.[15] Since the early 1990s, technology forecasting has regained its early popularity, to a large extent because technology developments have made it easier to apply forecasting techniques.[16]

A recurring topic in the literature on technology forecasting is the predictability of technology developments. To track and project the progress of technology, developments have to be predictable at some level. Since technological change represents the cumulative interaction of numerous technology developments, trends can be difficult to predict.[17] Technology developments also depend on natural and industrial resources.[18]

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[11] Jones and Twiss, *Forecasting Technology*, 31. The *Technology Forecasting and Social Change* journal was launched in 1969. In 1967, Jantsch identified hundreds of technology forecasting methods in use. Jantsch, E. Technological Forecasting in Perspective (Paris: OECD, 1967).
[12] Jones and Twiss, *Forecasting Technology*, 2-3.
[13] Harold A. Linstone, 'TFSC: 1969-1999', *Technological Forecasting and Social Change* 62 (1999): 3.
[14] Technology forecasting had been all but abandoned except for pockets of ongoing interest. Jones and Twiss, *Forecasting Technology*, 4-5; and Linstone, 'TFSC: 1969-1999', 4.
[15] Appropriate use includes predicting when a new process or product will be adopted, predicting developments and innovations in particular areas, and predicting changes in the direction of developments based on new combinations or potential capabilities. Makridakis, *Forecasting Methods,* 319.
[16] Technological advances in the speed of computing, the availability of inexpensive storage, and the ability to handle increasing layers of complexity have made the techniques for technology forecasting, many of which had been done by hand during the early development of forecasting, easier and more comprehensive. Joseph P. Martino, 'Thirty Years of Change and Stability', *Technological Forecasting and Social Change* 62 (1999): 17.
[17] Jones and Twiss, *Forecasting Technology*, 25.
[18] Complex changes that enabled industrialisation and urbanisation provided an infrastructure for the development of information technology. Buchanan used the development and diffusion of networked computers as an illustrative example. From the late 1980s into the 1990s, many organisations acquired the capability of networked computing. Buchanan's example illustrates that achieving this diffusion of networked computers required a sequence of developments in the materials needed to make the equipment, in the availability and delivery of electricity, in the capacity to produce the equipment, in corporate environments that demanded the diffusion, in transportation systems to deliver the equipment, in telecommunications to enable the exchange of information using the networks, in storage media to hold the information, in the skills to install and use the equipment, and other organisational and technological areas. Predicting the diffusion of

Some authors view the technological change process as a systematic and rational method that achieves specified goals; other authors perceive technological change as primarily the result of trial and error.[19] Some technology researchers believe that technological change is evolutionary and therefore predictable; others believe that it is revolutionary and therefore unexpected and unpredictable.[20] This is an important distinction to consider in devising the means to track technological change for digital preservation because evolutionary change is potentially predictable if the incremental steps leading to the change can be identified and observed; a revolutionary change would be produced by an unobservable or unpredictable development.

Since the early development of technology forecasting in the 1960s, more than a hundred forecasting techniques have been identified – so many that various authors have proposed classification schemes for forecasting techniques. Jones and Twiss categorised technology forecasting techniques by method, e.g., qualitative, quantitative, time and probability results, and defined a specialised purpose for each category of result. Qualitative techniques produce a narrative on the nature of the technology development; quantitative techniques describe the scale and capacity of the technology; time-related techniques suggest when the technology development is likely to be available or viable; and probability techniques consider the likelihood that the technology will become viable.[21] Makridakis classified technology

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networked computing capability would have required an awareness of developments in all of these areas. Buchanan, *The Power of the Machines*, 61, 76, 83, 94, 102, 114, 120, 122, 178-193.

[19] See for example: Elster, *Explaining Technical Change*, 9; David C. Mowery, and Nathan Rosenberg, *Paths of innovation: Technological Change in Twentieth Century America*, (Cambridge: Cambridge University Press, 1998), 123; and Thomson, *Learning and Technological Change*, 1. The purpose of one Web site is to continually identify emerging technologies that have the potential to be revolutionary or disruptive. Emerging Technology Watch, 'Innoblog', http://www.innosight.com/blog/ (accessed 10 May 2008).

[20] Authors who view technological change as predictable believe that every change has one or more developmental steps that lead to a change. From their perspective, technological change may seem sudden because the incremental steps were not observed before the impact of the change was perceived. See for example: Thomson, *Learning and Technological Change*, 9; Mowery and Rosenberg, *Paths of innovation*, 123; Jones and Twiss, *Forecasting Technology*, 22. Some authors acknowledge the potential for revolutionary change, but tend to conclude that the majority of technology developments are evolutionary. See for example: Buchanan, *The Power of the Machines*, xiii. A key assumption these authors make is that technology developments have a pattern that can be detected, that technology developments are not random and that "coming events cast their shadow". Jones and Twiss, *Forecasting Technology*, 53.

[21] Jones and Twiss, *Forecasting Technology*, 21.

forecasting techniques by intent, e.g., exploratory, normative.[22] Exploratory techniques look for trends and seek to understand developments relative to objectives; normative techniques seek technology developments that can be applied to meet specified objectives. Linstone classified technology forecasting techniques by perspective, e.g., technical, organisational, and personal. Technical techniques are exploratory; organisational techniques are normative; and personal techniques are perceptive.[23] In 2004, the Technology Futures Analysis Methods Working Group identified families of techniques that can be characterised as hard (quantitative) or soft (qualitative), and exploratory or normative.[24] The digital preservation community might use exploratory techniques to identify technology developments with implications for preserving digital content and normative techniques to determine appropriate responses to technology developments and to seek technology developments to enable and enhance digital preservation practices. The following examples consider the applicability of five technology forecasting techniques for digital preservation purposes: brainstorming, gap analysis, pattern analysis, roadmaps, and Delphi. A common characteristic of these techniques is that minimal resources are needed to produce useful outcomes.[25]

Brainstorming is an exploratory forecasting technique to generate new ideas through the interaction of creative and receptive thinkers.[26] The brainstorming method can be effective for considering alternatives to address problems and for identifying new products, procedures, and processes; it has proven less effective for problems that have only one answer or are overly complex.[27] Brainstorming has become a familiar technique in many domains and is already in use within the digital preservation community. In 2003, the digital preservation community released two research agenda reports, *It's About Time* and *Invest to Save*, which used brainstorming as one technique for gathering data, defining the scope of the

[22] . Makridakis, *Forecasting Methods*, 319.
[23] Linstone, 'TFSC: 1969-1999', 4.
[24] Technology Futures Analysis Methods Working Group, 'Technology Futures Analysis', 290.
[25] The literature of the digital preservation community includes no substantive or comprehensive discussion of the utility or applicability of technology forecasting techniques. This section notes examples in which forecasting techniques have been applied for digital preservation purposes.
[26] Brainstorming is a forecasting technique that was introduced by Osborn in 1938 to identify alternatives for solving a specific problem. Jones and Twiss, *Forecasting Technology*, 98-99.
[27] Jones and Twiss, *Forecasting Technology*, 102.

problem, and developing recommendations.[28] Brainstorming could be used more routinely and systematically by the digital preservation community to establish and review priorities and objectives, to consider alternative digital preservation strategies, and to scope specific problems relating to technology developments.

Gap analysis is a normative forecasting technique that is used in a variety of management areas for activities such as market analysis or as a starting point for planning.[29] Gap analysis for technology forecasting typically looks ahead ten to fifteen years.[30] Gap analysis has been used within the digital preservation community to assess procedural capabilities and standards compliance. For example, the TRAC document is based on a gap analysis process using the results of a self-assessment of the digital repository.[31] Gap analysis is presented to participants in the Digital Preservation Management workshop as a technique for programme development and as an approach to investigate new and emerging technology developments for digital preservation.[32] Gap analysis could also be applied for digital preservation purposes to consider the capabilities of technology developments during assessments and to look for technology developments that address identified limitations in capabilities.[33]

Pattern analysis is an exploratory forecasting technique that can be applied to accumulations of information to identify trends, detect new developments, and

[28] The use of this approach was confirmed in conversations by the author of this thesis with Margaret Hedstrom, author and co-author of the reports. Margaret L. Hedstrom, interview by author, 20 May 2008. NSF and DELOS, *Invest to Save*; and NSF and NDIIPP, *It's About Time*.
[29] According to Jones and Twiss, Jantsch is the likely innovator who first applied the gap analysis to technology developments in 1972. Jantsch based his approach on Mendelev's Periodic Table developed in 1869. The process of placing known elements in sequence enabled the identification of new elements by their observed absence. Jones and Twiss, *Forecasting Technology*, 128-136. In digital preservation, storage media is a possible candidate for gap analysis. For example, if current examples of storage media were sequenced by size, capacity, and other characteristics, new or anticipated alternatives might emerge.
[30] Joseph T. Coates, 'Boom Time in Forecasting', *Technological Forecasting and Social Change* 62 (1999): 38.
[31] The author of this thesis was a member of the task force that produced the TRAC document. OCLC and CRL, TRAC, http://www.crl.edu/PDF/trac.pdf (accessed 10 May 2008).
[32] The author of this thesis is a co-developer of the Digital Preservation Management workshop series with Anne R. Kenney, University Librarian at Cornell University Library. Kenney and McGovern, *Digital Preservation Management*, http://www.icpsr.umich.edu/dpm/ (accessed 1 May 2008).
[33] Section 2.6 discussed the development of an inventory of technology developments and Section 2.7 discussed the means to prioritise technology developments for assessment and response.

highlight issues for analysis, for example.[34] Access to the accumulation of current and historical information enables the identification of patterns.[35] Documenting digital preservation strategies will require direct access to the information sources to understand the basis for the recommendations and to evaluate the information. A challenge in applying pattern analysis is making inappropriate connections that lead to incorrect pattern identification.[36] This limitation in pattern analysis can be offset by identifying as many steps in development for a technology as possible and verifying the patterns through the application of other techniques.[37] The review of digital preservation literature identified no explicit references to pattern analysis, although informal uses of pattern analysis occur in any identification of trends and other patterns.[38] The ability to search for patterns in technology developments using criteria that reflect digital preservation objectives would contribute an essential component of a comprehensive technology response for digital preservation.[39]

A *roadmap* is a technology forecasting tool that can be used to illustrate technology trends and interactions between technology developments.[40] Over the past decade, roadmaps have appeared in the technology forecasting literature with increasing regularity. Roadmaps provide a flexible technique for communicating a lot of information visually, although some roadmaps are more text-based than

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[34] Anil K. Jain, Robert P.W. Duin, and Jianchang Mao, 'Statistical Pattern Recognition: A Review', *IEEE Transactions on Pattern Analysis and Machine Intelligence* 22, no. 1 (2000): 4 - 37. Section 3.5 discusses the technology advances that have enabled pattern analysis using text mining.

[35] Jones and Twiss, *Forecasting Technology*, 94-95.

[36] Makridakis, *Forecasting Methods*, 38.

[37] Martino, 'Thirty Years of Change and Stability', 15.

[38] For example, Ross announced the development of a technology roadmap for digital curation by Digital Preservation Europe. Seamus Ross, 'Exploring and Charting the Digital Preservation Research Landscape', presented at the International Conference on Preservation of Digital Objects (iPres) 2007 Conference in Beijing, China, October 11-12, 2007, http://ipres.las.ac.cn/program.jsp (accessed 10 January 2008).

[39] Section 2.6 identified technology developments and functions that are potentially relevant for digital preservation and Section 2.7 discussed criteria to prioritise the detected technology developments, for example.

[40] Bruce A.Vojak, and Frank A. Chambers, 'Roadmapping Disruptive Technical Threats and Opportunities in Complex, Technology-based Systems', *Technological Forecasting and Social Change* 71 (2004): 122. Roadmaps for evaluating technology impacts first emerged in the automotive industry during the late 1970s and early 1980s. Robert Phaal, Clare J.P Farrukh, and David R. Probert, 'Technology Roadmapping – 'A Planning Framework for Evolution and Revolution', *Technological Forecasting and Social Change* 71 (2004): 10. Rinne noted that "technology roadmaps are gaining momentum because they connect technologies, products, and markets at the right level of abstraction". Martin Rinne, 'Technology Roadmaps: Infrastructure for Innovation', *Technological Forecasting and Social Change* 71 (2004): 79.

visual.[41] The focus of roadmaps can range from very broad, e.g., for an industry, to very narrow, e.g., for a specific technology.[42] Some examples of industry roadmaps produced by technology forecasting are available.[43] The two research agenda reports, *It's About Time* and *Invest to Save*, are narrative roadmaps for the digital preservation community that could be translated into high-level visual roadmaps. Another example is the Digital Preservation Europe report on technologies for digital curation.[44] These examples suggest that roadmaps could be useful for community-wide digital preservation planning as technology evolves.

Delphi is a probability technique for technology forecasting that involves iterative opinion polling to predict technology trends and developments.[45] As with other forecasting techniques, Delphi results need to be confirmed by applying other techniques.[46] The ease of applying the Delphi technique by convening expert panels led to its overuse and unconfirmed results, which contributed to a decrease in its use and criticisms of technology forecasting more generally.[47] Kuusi and Meyer noted a resurgence in Delphi use to identify nation-wide trends during the 1990s.[48] Expert

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[41] Improved technologies for visualising information have led to the increased use of roadmaps and to the specification of the process for developing roadmaps and the definition of different types of roadmaps. Roadmaps can illustrate technology developments at a point in time or evolution over a span of time. Roadmaps can be used to present the results of other forecasting techniques, e.g., pattern analysis. The graphical component of roadmaps builds on PERT and Gantt diagrams. Phaal, Farrukh, and Probert, 'Technology Roadmapping', 10.

[42] Roadmaps can be used for forecasting, planning, and administration purposes and can present relevant information in topical layers. Sungjoo Lee,, and Yongtae Park, 'Customization of Technology Roadmaps According to Roadmapping Purposes: Overall Process and Detail Modules', *Technological Forecasting and Social Change* 72 (2005): 573.

[43] For example, a Software Technology Roadmap was developed in the academic rather than commercial sector, although the Software Engineering Institute that produced the roadmap was interested in using the roadmap to promote viable applications. Software Engineering Institute, 'Software Technology Roadmap', Carnegie Mellon University, http://www.sei.cmu.edu/str/taxonomies/index.html (accessed 11 November 2007).

[44] The development was announced in: Ross, 'Exploring and Charting the Digital Preservation Research Landscape'.

[45] Helmer confirmed that Delphi was developed by Olaf Helmer and Norman Dalkey in 1953 at Rand. Woudenberg noted that the Delphi technique was named after the Greek oracle at Delphi. Olaf Helmer, Looking Forward: A Guide to Futures Research (Beverly Hills: Sage Publications, 1983); and F. Woudenberg, 'An Evaluation of Delphi', Technological Forecasting and Social Change 40 (1991): 131-150.

[46] Coates, 'Boom Time in Forecasting', 38. Two probability approaches have appeared within the last decade that offset the limitations of the Delphi technique. These are the *probabilistic trend* that targets the time intervals between advances and *probabilistic time lags* that calculate time lags, two difficult aspects of technology to predict. Martino, 'Thirty Years of Change and Stability', 16-17.

[47] Jones and Twiss, *Forecasting Technology*, 66, 153-154.

[48] Osmo Kuusi, and Martin Meyer, 'Technological Generalizations and Leitbilder – The Anticipation of Technological Opportunities', *Technological Forecasting and Social Change* 69 (2002): 626.

panels on digital preservation have been used to produce digital preservation standards and practice.[49] Delphi could be used more broadly by the digital preservation community for responding to technology, if the expert recommendations are confirmed through pattern analysis, gap analysis, and other techniques.

Technology forecasting literature includes numerous discussions and comparisons of forecasting techniques, examples of applying techniques, and approaches for combining techniques.[50] The investigation of technology forecasting literature documented that techniques for forecasting have been established and refined, but the presentation of the results of forecasting has not typically been formalised. One exception is the report template proposed by the JTC 1 Technology Watch initiative, which addresses the needs of the information technology community, and is a potential technology forecasting model for other communities to adapt. The JTC 1 report template includes a detailed technology forecast, including a statement of the forecast, the rationale for the forecast, a statement about the probability and timing of the emergence of the development, opportunities and threats posed by the technology development for information technology initiatives, and the potential impact of the technology development for the interests of the information technology community.[51] The JTC 1 work was the most explicit example identified of an attempt to standardise the reporting of technology forecasting.

The investigation of technological change suggested that when technological change is evolutionary rather than revolutionary, it should be possible

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[49] For example: The *OAIS Reference Model*, and the two research agenda reports, *It's About Time* and *Invest to Save*, convened expert panels. The *DigiCULT Technology Watch Reports* specifically used expert panels to identify technology developments to review.

[50] An early example is the comprehensive discussion of forecasting techniques and applications by Jones and Twiss. A notable more recent example is the work of the Technology Futures Analysis Methods Working Group that produced a report on the purpose, scope, process, format, and performance of technology forecasting. Jones and Twiss, *Forecasting Technology*; and Technology Futures Analysis Methods Working Group, 'Technology Futures Analysis', 292-294.

[51] The technology taxonomy of the JTC 1 Technology Watch was introduced in Section 2.5 as an example from another community that might be adapted for digital preservation. Coallier, 'JTC 1 Technology Watch'.

to predict the emergence of technology developments.[52] Systematic monitoring might highlight converging developments or a sequence of incremental changes that would enable forecasting. The history of forecasts has demonstrated that it may be possible to predict that a development will occur, but it is often not possible to predict exactly when it will occur.[53] It is more important in the context of digital preservation to be able to determine that a technology development will emerge than it is to be able to predict when, because digital preservation occurs over decades rather than years, unlike typical business timeframes. The potential to develop the ability to trace and to some extent predict technology developments represents a key aspect of developing a comprehensive approach to technology responsiveness for digital preservation.

3.3 Technology Assessment

Technology assessment is a process to identify the potential impacts of emerging technologies and recommend community response, often to prevent possible negative impacts.[54] This technology response type emerged in the 1960s along with computer technology, particularly in response to concerns over space science developments.[55] Information about technology assessment is located in the literature of many domains, including the history of technology, the philosophy of technology, sociology, and information science. The discussion of technology assessment in this section refers to the results of a review conducted for this research of technology assessment literature and programmes.

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[52] Section 2.2 discussed technological change as evolutionary and revolutionary. Section 2.3 discussed the technology innovation stages for the emergence and evolution of technology and the human factor as a challenge for predicting technology developments. The human factor is further discussed in Section 3.6.

[53] Frederich Rapp, 'The Prospects of Technology Assessment', in *Philosophy and Technology*, Paul T. Durbin, and Friedrich Rapp, eds., 1983 (Dordrecht: Reidel, 1983), 14.

[54] The possible benefits of technology assessment for digital preservation were referenced in Section 1.7, along with its potential to supplement existing archival appraisal practices, for example. Technology assessment is further referenced in the *assess* stage of the technology response model in Section 4.8, and demonstrated by the object-based technology response example that is discussed in Chapter 5. Technology assessment is discussed more generally in this section as a technology response practiced by other communities.

[55] Jones and Twiss, *Forecasting Technology*, 2.

In the 1960s, concern grew about the impact of technology on the environment and on society.[56] The increased demand for power to support computer developments and associated environmental concerns caused particular concern.[57] Movements such as appropriate technology and alternative technology addressed ways in which the potential detrimental side effects of technology could be minimised.[58] These concerns led to the development of technology assessment, a type of policy analysis.[59] Technology assessment requires that any assumptions made as a basis for recommendations be made "explicit and precise" so that the results of the technology assessment will be as neutral as possible.[60] These requirements align with established principles and practice of the digital preservation community. Neutrality is an expectation in the development of digital preservation strategies and documenting preservation decisions is an audit requirement.[61]

The review of technology assessment identified programmes in many organisational contexts. It is common for universities, particularly larger institutions, to have technology assessment programmes.[62] There are technology

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[56] Linstone, 'TFSC: 1969-1999', 3.
[57] Mowery and Rosenberg, *Paths of innovation*, 165.
[58] Buchanan, *The Power of the Machines*, 248.
[59] Critics of the technology assessment expressed concern over the neutrality of the process, particularly when the outcomes of technology assessment had significant economic implications. Rapp, 'Prospects of Technology Assessment', 145.
[60] Stanley R. Carpenter, 'Techoaxiology: Appropriate Norms for Technology Assessment:', in *Philosophy and Technology*, Paul T. Durbin, and Friedrich Rapp, eds., (Dordrecht: Reidel, 1983), 115-116.
[61] Procedural accountability is an attribute of a trusted digital repository and the TDR document informed the development of the TRAC checklist, as well as the ISO standards development project for repository audit and certification. RLG and OCLC, Trusted Digital Repositories' (RLG and OCLC: Mountain View, CA, 2002); *TRAC*, http://www.crl.edu/PDF/trac.pdf (accessed 10 May 2008); and Digital Repository Audit and Certification (RAC) Working Group, "Digital Repository Audit and Certification" http://wiki.digitalrepositoryauditandcertification.org/bin/view (accessed 10 May 2008).
[62] The Science and Technology Policy Research programme (SPRU) was established at the University of Sussex in the 1960s to perform technology innovation and technology assessment; the Policy Research in Engineering, Science and Technology (PREST) was established at the University of Manchester in the 1970s. University of Sussex, Science and Technology Policy Research programme (SPRU), http://www.sussex.ac.uk/spru/ (accessed 10 May 2008); University of Manchester, Policy Research in Engineering, Science and Technology (PREST), http://www.mbs.ac.uk/research/engineeringpolicy/index.aspx (accessed 10 May 2008). The *4Teachers* Web site provides uses technology assessment to support the integration of technology into the classroom. *4Teachers*, http://www.4teachers.org/inttech/ta.php (accessed 10 May 2008). The University of Wollongong in Australia has a technology assessment project entitled 'Technology Assessment in its Social Consequences (TASC)', to develop a comprehensive approach to technology assessment for policy development. University of Wollongong, 'Technology Assessment

assessment examples in the commercial sector as well.[63] Technology assessment programmes often exist at the national level of government.[64] In addition to these programmes, there are examples of professional societies and journal publications on technology assessment, including several long-running journals and an international journal launched in 2005, which document the development of technology assessment.[65] For the most part, the literature on technology assessment

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that considers the Social Consequences (TASC)' http://www.utas.edu.au/ruralcommunities/TASC/ (accessed 10 May 2008).

[63] One example is a technology assessment toolkit, a product Microsoft provides to small businesses to identify the technology needs of customers. Microsoft Partners Program, 'Technology Assessment Toolkit', https://partner.microsoft.com/40025740 (accessed 10 May 2008).

[64] For example, the Parliamentary Office of Science and Technology (POST) has been providing technology assessment services for the Parliament since 1989 and contributes to the work of the newly established European Parliamentary Technology Assessment (EPTA) partners. POST's technology assessment reports and briefing reports, called *POSTnote*, combine explanation and recommendations. Parliamentary Office of Science and Technology (POST), http://www.parliament.uk/parliamentary_offices/post/about5.cfm (accessed 10 May 2008); European Parliamentary Technology Assessment (EPTA), http://www.eptanetwork.org/EPTA/ (accessed 10 May 2008). The National Health Service has a technology assessment programme to assess the impact of health technologies. National Health Service, 'NIHR Health Technology Assessment Programme', National Institute for Health Research, http://www.hta.ac.uk/ (accessed 10 May 2008). In the USA, the Office of Technology Assessment (OTA) provided technology assessment support for the US Congress from 1972 to 1995. Princeton University, 'The OTA Legacy', http://www.princeton.edu/~ota/ (accessed 10 May 2008). There have been unsuccessful efforts to revive OTA. For example, there was an attempt to resurrect OTA in the American Institute for Physics (AIP). 'House Rejects Rep. Holt Amendment to Establish OTA-Capability', *Bulletin of Science Policy News*, http://www.aip.org/fyi/2004/116.html (accessed 10 May 2008). Several federal agencies have established their own technology assessment programmes. There are health-related technology assessment programmes, including a programme at the Office of Patient Care Services of the Department of Veteran Affairs, VATAP; the Heath Services Technology Assessment Texts (HSTAT) at the National Library of Medicine; and the Agency for Healthcare Research and Quality (AHRQ) for the Medicare programme. Health-related issues are increasingly the focus of technology assessment, as evidenced by Health Technology Assessment International (HTAI), established in 2003. Health Technology Assessment International (HTAI), http://www.htai.org/ (accessed 10 May 2008).The Bureau of Industry and Security (BIS) of the US Department of Commerce conducts broad technology assessments at the national level to address technology export issues; and the US Global Change Research Program (USGCRP) considers the impacts of technology on global climate. US Department of Commerce, Bureau of Industry and Security (BIS), http://www.bis.doc.gov/about/bisguidingprinciples.htm (accessed 10 May 2008); and US Global Change Research Program (USGCRP), http://www.usgcrp.gov/usgcrp/default.htm (accessed 10 May 2008). The International Center for Technology Assessment (CTA) is a non-profit organisation established by 2002 that explores the "ethical, social, environmental and political" impacts of technology. International Center for Technology Assessment (CTA), http://www.icta.org/template/index.cfm (accessed 10 May 2008).

[65] The Society for Social Studies of Science (4S) was established in 1975 to promote and understanding of science and technology. Society for Social Studies of Science (4S), http://4sonline.org/ (accessed 10 May 2008). There are two long-running international journals for technology assessment; the *Science, Technology & Human Values* (ST&HV) journal has been published since 1976 and the *Technology in Society* journal since 1979. *Science, Technology & Human Values* (ST&HV), http://sth.sagepub.com/ (accessed 10 May 2008); *Technology in Society*, http://www.elsevier.com/wps/find/journaldescription.cws_home/384/description#description (accessed 10 May 2008). *Poiesis & Praxis*: *The International Journal of Ethics of Science and Technology Assessment* was launched in 2001. Poiesis and Praxis are Greek terms for theory and practice. *Poiesis & Praxis*: *The International Journal of Ethics of Science and Technology*

discusses the outcomes of technology assessment, rather than specifying how technology assessments are completed or identifying common practices and models for conducting technology assessments.

The survey of government technology assessment programmes identified one example of a technology assessment procedure, the *Technology Readiness Assessment (TRA) Deskbook*.[66] The objective of the programme is to "integrate advanced technology into producible systems and deploy these technologies in the shortest time practicable".[67] More importantly for this evaluation of technology responses for digital preservation, TRA also ensures that critical technologies are mature enough before integration by defining nine levels of technology readiness from conceptualisation of the technology to its final application.[68] Technology readiness levels have also been applied to assessing the needs and necessary competencies of users of technology.[69] The TRA approach and the associated assessment of user readiness for emerging technologies are very relevant to the development of technology responsiveness for digital preservation. The readiness levels could be considered during technology assessments of technology developments for digital preservation, and the technology readiness surveys could be used to survey the readiness of the digital preservation community for the emergence of technologies.

Assessment, http://www.springer.com/west/home/physics?SGWID=4-10100-70-1151372-0 (accessed 10 May 2008); The *Australian Journal of Emerging Technologies and Society* (AJETS) was established in 2003 and the *International Journal of Technology and Human Interaction* (IJHTI) began exploring the human aspects of technology assessment in 2005. *Australian Journal of Emerging Technologies and Society* (AJETS), http://www.swin.edu.au/sbs/ajets/about.htm (accessed 10 May 2008); and *International Journal of Technology and Human Interaction* (IJHTI), http://www.idea-group.com/journals/details.asp?id=4290 (accessed 10 May 2008).

[66] US Department of Defense, *Technology Readiness Assessment (TRA) Deskbook,* Deputy Undersecretary of Defense for Science and Technology, https://acc.dau.mil/CommunityBrowser.aspx?id=18545 (accessed 10 May 2008).

[67] *Technology Readiness Assessment (TRA) Deskbook*,. 1-3.

[68] TRA levels of Readiness, *Technology Readiness Assessment (TRA) Deskbook,* A-12. The TRA readiness levels establish metrics for measuring the development of technologies that build on the stages of the innovation cycle that was introduced and discussed in Section 2.3. Other readiness approaches have been proposed to manage technology as it evolves. For example, James D. Smith,, II, An Alternative to Technology Readiness Levels for Non-Developmental Item (NDI) Software', *Proceedings of the 38th Hawaii International Conference on System Sciences*, 2005, 3.

[69] Nikos Tsikriktsis, 'A Technology Readiness-based Taxonomy of Customers: A Replication and Extension', *Journal of Service Research* 7, no. 1 (2004): 42-52. The National Technology Readiness Survey is a nation-wide survey that has been conducted annually since 2001. Robert H. Smith School of Business, 'National Technology Readiness Survey', http://www.rhsmith.umd.edu/ces/ntrs.html (accessed 10 May 2008).

Many fields use a form of technology assessment called evaluation that documents the context of the situation being assessed.[70] The evaluation process includes the definition of the requirements for the results of the evaluation and incorporates an audit process to monitor and test the results.[71] Impact assessment is another technique for assessing the implications of technology, although it has been mostly heavily used in the environmental sciences to consider potential negative impacts on the environment.[72] The desired outcome of technology assessment for digital preservation is to develop and enhance the means to preserve digital content as technology evolves.[73] This objective parallels the intended outcomes of technology assessment, evaluation, and impact assessment. The need to test conclusions and recommendations by measuring actual outcomes and impacts is an important consideration in applying these technology response examples to digital preservation.

3.4 Technology Transfer

Technology transfer is "the process by which practical knowledge is acquired, developed, and put to use in a context other than the one in which it was organized".[74] Technology transfer initially referred to the capability of one domain to reuse the technology developments of another domain through adoption, adaptation, and the development of new technology based upon the technology

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[70] Guba noted that evaluation is used by many professionals that rely upon case studies, such as social workers, parole officers and others. Evaluators use observation and the compilation and analysis of data. Evaluation is relevant to technology assessment because it has similar principles and outcomes, but evaluation is always applied to technology. Evaluation began in education as an approach for measuring student progress in the 1890s. It was later adapted for personnel evaluations. The time management movement in the 1930s and 1940s contributed measurement to evaluation. Egon G. Guba, and Yvonna S. Lincoln, *Fourth Generation Evaluation* (Newbury Park, CA, USA: Sage Publications, 1989), 24-27, 139.

[71] Guba, *Fourth Generation Evaluation*, 248.

[72] 'Documents and Information Repositories on Impact Assessment', Urban Environmental Management, http://www.gdrc.org/uem/eia/define.html (accessed 20 May 2008). An example of an impact assessment program is the International Association for Impact Assessment (IAIA), established in 2005. International Association for Impact Assessment (IAIA), http://www.iaia.org/ (accessed 20 May 2008).

[73] Technology assessment for digital preservation was introduced and discussed in Section 1.7.

[74] Bauer, et al, *Second Order Consequences*, 175. The National Air and Space Administration (NASA) in the 1960s provided an early example of potential technology transfer with an analysis of the potential benefits and disadvantages of the secondary adaptation of space technology. Floridi, *Philosophy and Computing*, 1.

developments.[75] This response is a technique used in many domains, but practiced with the greatest frequency by the disciplines included in engineering.[76] Although technology transfer is often referred to in the literature, the actual techniques to enable technology transfer from one domain or institution to another are still being formalised, do not yet have universal definitions or protocols, and may vary from domain to domain.[77]

Like technology forecasting, the primary objective of technology transfer is to realise tangible benefits from technology developments.[78] Unlike technology forecasting, the technology developments that become candidates for technology transfer must already exist rather than be on the horizon and the benefits of technology transfer may be realised more through savings on development costs and through process improvements than through profits.[79] Technology transfer is more than just information exchange; it is adopting or adapting the knowledge or practice of one domain to meet the requirements of another domain.[80]

Technology transfer can involve a transformation of an existing technology, the identification of its implications for use in another context, or the definition of a process to implement the resulting innovation. There are two types of technology transfer: *cognitive transfer* involves understanding the way things are done in another domain; and *operational transfer* applies that understanding to adapt or develop needed techniques and procedures.[81] Technology transfers can be vertical – moving from theory to practice or from general to specific applications – or horizontal – moving from one context to another through the identification of analogous institutions and relevant practices.[82] Finding one analogous development

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[75] Bauer, et al, *Second Order Consequences*, 175.
[76] Gorschek, Tony, Per Garre, Stig Larsson, and Claes Wohlin, 'A Model for Technology Transfer in Practice', *IEEE Software* 23, no. 6, (2006): 88 – 95.
[77] Mishra, Somnath, S.G., Deshmukh, and Prem Vrat, 'Matching of Technological Forecasting Technique to a Technology', *Technological Forecasting and Social Change* 69 (2002): 5. For an example of a proposed technology transfer model, see: Gorschek, Tony, et al., 'A Model for Technology Transfer in Practice'.
[78] See for example: Bauer, et al, *Second Order Consequences*, 165; and Porter, Alan L. 'Depth Perception', *Technological Forecasting and Social Change* 62 (1999): 144.
[79] Jones and Twiss, *Forecasting Technology*, 109.
[80] Bauer, et al, *Second Order Consequences*, 166-167.
[81] Bauer, et al, *Second Order Consequences*, 165; and Jones and Twiss, *Forecasting Technology*, 112-118.
[82] Bauer, et al, *Second Order Consequences*, 166-167.

can lead to other analogies by scanning that community more broadly.[83] Identifying opportunities for technology transfer requires two components: a "systematic knowledge" of the donor technology, which means acquiring a deep understanding of the purpose and functionality of the potential technology to be transferred from another community; and a definition of the "idiosyncratic components" of the recipient requirements, which means stipulating the requirements for the gap or need that will be filled or met by a technology in another community.[84] One consequence is that technology transfer may introduce technological change more quickly than expected in a domain and therefore complicate the prediction of the emergence of technology developments.[85] A technology development in one domain might remove a barrier in another domain that had been preventing a potential development from being implemented.[86]

The investigation of technology transfer identified examples of programmes in several organisational contexts. Technology transfer offices often exist at the national level of government to promote research and development and to maximise a government's investment in research.[87] The Science and Development Network is

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[83] Jones and Twiss, *Forecasting Technology*, 112-118.
[84] Bauer, et al, *Second Order Consequences*, 182.
[85] Section 3.2 discussed the predictability of the emergence of technology developments. In this context, the factor affecting predictability is an unexpected adaptation from one domain to another. For example, developments that made television possible were adapted for use in computer monitors. Buchanan, *The Power of the Machines*, 163. A community that was tracking computers at that time might have been surprised by that development. The development of the typewriter provided the components and capabilities of the now familiar computer keyboard, which with the mouse, enabled users to interact with computers. Earlier developments were adapted for use in the development of newer technologies. Floridi, *Philosophy and Computing*, 54.
[86] For example: Elster, *Explaining Technical Change*, 95; and Mowery and Rosenberg, *Paths of innovation*, 123. Relative to digital preservation, increases within the past five years in the capacity of computer networks to exchange information has enabled the creation and use of larger file formats, e.g., video files, audio files, geospatial files, three-dimensional visualisations. These are all current areas of growth for digital content. An increase in network capacity is one factor enabling that growth. A technology assessment of each of those digital content types would identify additional factors.
[87] The Department for Business Enterprise and Regulatory Reform (BERR) promotes technology transfer; the University of Oxford and other universities maintain technology transfer office; the Technology Transfer Training Programme, Praxis, supports technology transfer in universities; and the Wellcome Trust, an independent charity that funds research, has a technology transfer Web site and guide to encourage technology transfer. UK Department for Business Enterprise and Regulatory Reform (BERR), http://www.berr.gov.uk/about/index.html (accessed 20 May 2008); Oxford Innovation Society, University of Oxford, http://www.isis-innovation.com/about/ois.html (accessed 20 May 2008); Praxis, Technology Transfer Training Programme, http://www.praxiscourses.org.uk/ (accessed 20 May 2008); and Wellcome Trust, 'Technology Transfer', http://www.wellcome.ac.uk/Funding/Technology-transfer/ (accessed 20 May 2008). In the USA, there is a government-wide technology transfer network, the Federal Laboratory Consortium for

coordinating an international technology transfer effort to provide the benefits of technology transfer for developing countries.[88] Most of these programmes have a primary objective of attaining patents and licenses for research results, but some offer training programmes and supplementary programmes that focus on the process and method of technology transfer. Technology transfer programmes, particularly in the academic setting, often highlight the potential economic benefits of technology transfer through licenses for research results.[89] In addition to looking at technology transfer programmes, the investigation of technology transfer for digital preservation identified several long-running journals and a recently launched international journal on technology transfer.[90] The authors discuss management

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Technology Transfer (FLC), the National Technology Transfer Center (NTTC),and a number of technology transfer offices in federal agencies, including the National Institutes of Health (NIH), the Department of Agriculture (USDA), and the Environmental Protection Agency (EPA). Federal Laboratory Consortium for Technology Transfer (FLC), http://www.federallabs.org/ (accessed 20 May 2008);.National Technology Transfer Center (NTTC) http://www.nttc.edu/ (accessed 20 May 2008); National Institutes of Health (NIH), http://ott.od.nih.gov (accessed 20 May 2008); Department of Agriculture (USDA), http://www.nal.usda.gov/ttic/ (accessed 20 May 2008); and Environmental Protection Agency (EPA), http://www.epa.gov/ttbnrmrl/ (accessed 20 May 2008).

[88] Science and Development Network, http://www.scidev.net/en/ (accessed 20 May 2008).

[89] The use of the term technology transfer in academic contexts might be narrowed to refer to the transfer of rights from the creators of the technology to the adapters of the technology, generally from a research group to a production group, as the following examples illustrate. One example of technology transfer from the Association of University Technology Managers describes the technology transfer process as consisting of three stages: disclosing information about an innovation, obtaining a patent for the innovation, and enacting a license for using the innovation. “Academic institutions have seen a significant increase in technology transfer activity. For example, before 1980, fewer than 250 patents were issued to U.S. universities each year … in FY 2002, AUTM members reported that 5,327 new license agreements were signed. Between FY 1991 and FY 2004, annual invention disclosures increased more than 290 percent (to 18,178), new patents filed increased nearly 450 percent (to 11,089), and new licenses and options executed increased about 510 percent (to 5,329)”. Association of University Technology Managers (AUTM), Frequently Asked Questions (FAQ): ‘Has there been growth in academic technology transfer programs?’, http://www.autm.net/aboutTT/aboutTT_faqs.cfm (accessed 20 May 2008). The AUTM attributes this focus on licenses to the 1980 Bayh-Dole Act, which allowed federally-funded research to be patented and not pass directly into public domain. The manual AUTM produces for technology transfer focuses almost entirely on patents and licenses. Association of University Technology Managers (AUTM), *AUTM Technology Transfer Practice Manual*, 2nd Edition, http://www.autm.net/about/dsp.Detail.cfm?pid=44 (accessed 20 May 2008). A proposed technology transfer model matches research to industry interests. Gorschek, Tony, et al., ‘A Model for Technology Transfer’, 88.

[90] The *Journal of Technology Transfer* has been published since the 1970s, but the *International Journal of Technology Transfer and Commercialisation* and the *International Journal on Software Tools for Technology Transfer* (STTT) were both launched in 2002, the *Comparative Technology Transfer and Society* journal began in 2003. *Journal of Technology Transfer*, http://springerlink.metapress.com/content/1573-7047/ (accessed 20 May 2008); *International Journal on Software Tools for Technology Transfer* (STTT), http://sttt.cs.uni-dortmund.de/about-this-journal.html (accessed 20 May 2008); *Comparative Technology Transfer and Society*, http://muse.jhu.edu/journals/comparative_technology_transfer_and_society/toc/ctt1.1.html (accessed 20 May 2008); and *International Journal of Technology Transfer and Commercialisation*, http://www.inderscience.com/browse/index.php?action=articles&journalID=29 (accessed 20 May

issues pertaining to technology transfer, provide case studies about technology transfer applications, and discuss the tensions between commercial and academic objectives.

Analogies are used in technology forecasting, but they have broader applications for technology transfer between communities by matching technology capabilities with community needs. Historical analogies, such as the parallels between developments in railways and space travel, allow for the comparison of similar technologies and may identify current technologies as technology transfer candidates.[91] The use of analogies is an example of adaptation. There are specialised methods for incorporating the use of analogies.[92] An extension of adapting existing technologies is the combination of existing technologies to form new technologies, a process recently christened "technology fusion".[93] There is no common methodology for developing and using analogies, but specialised methods might be adaptable for digital preservation. The University of Southern California developed a method for describing available patents to characterise the developments and to highlight possible applications of technology developments that may not have been intended by the developers.[94] If this approach were adopted for describing patented developments, it might be possible for digital curators to identify technology transfer candidates for digital preservation more easily.[95]

2008). These journals do not focus only on information technology, but the technology transfer examples are informative for considering applications of technology transfer for digital preservation.

[91] Bauer, et al, *Second Order Consequences*, 33-37.

[92] Examples include: Ellen Domb, 'Using Analogies to Develop Breakthrough Concepts', *TRIZ*Journal [Theory of Inventive Problem Solving] (1998), http://triz-journal.com/archives/1998/04/e/index.htm (accessed 25 May 2008); and Dahl, Darren W. and Page Moreau, 'The Influence and Value of Analogical Thinking During New Product Ideation', *Journal of Marketing Research* 39, no. 1 (2002): 47-60.

[93] Porter, 'Depth Perception', 144.

[94] The Engineering Technology Transfer Center at the University of Southern California developed this method. An example they use is the developers of an engine might focus on the fact that the engine they developed resists fire, but the description of the invention might also note that the light weight of the engine, a characteristic that is of greater interest to some developers. Ken Dozier, the Director of the ETTC at USC, led a discussion of technology transfer at the 2002 Digital Government Online Conference and described the USC approach to technology transfer. The author of this thesis attended the session. University of Southern California, 'Technology Transfer Center', http://ttc.usc.edu/introduction/ (accessed 20 May 2008).

[95] The USC approach might highlight aspects of technology developments that make it easier to preserve digital information, e.g., methods for managing metadata for digital objects, or methods for persistent storage of digital content. Section 2.6 discussed keywords for identifying technology developments of interest and identified technology developments and functionality that are potentially relevant for digital preservation. These could provide the means to identify relevant technology developments in enhanced patent descriptions. In the digital preservation community, the

Technology transfer of selected technology developments from other domains offers the potential to reduce the costs of development for digital preservation strategies. The absence of extensive discussions in the literature about the means and mechanisms to translate technologies from one domain to another may make the benefits of technology transfer more difficult to imagine and to realise for digital preservation. In contrast, applying technology forecasting to digital preservation may be more easily envisioned because there are already some examples.

3.5 Technology Monitoring

Technology monitoring is the means to detect and track technologies of interest.[96] It is the technology response that is most applied but least covered in the literature. The initial interest in monitoring technologies to provide current information and advice about ongoing technology developments emerged in the 1960s when information technologies were moving into mainstream use.[97] These early approaches for tracking technology developments challenged the hardware and software capacity of the time.[98] The limited capabilities of information technology at that time failed to produce useful or scalable results, which meant that for the most part technology monitoring implementations were undertaken only by institutions with sufficient motivation and resources.[99] With the Internet, the potential to achieve some of these desired capabilities resurfaced, and the advent of

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PANIC project in Australia is developing an approach for describing Web services for digital libraries and preservation to be able to match their requirements to available tools. Hunter, Jane and Sharmin Choudhury, 'PANIC – An Integrated Approach to the Preservation of Composite Digital Objects using Semantic Web Services', *5th International Web Archiving Workshop* (IWAW05), http://www.iwaw.net/05/papers/iwaw05-hunter.pdf (accessed 20 May 2008). Two possible applications of the approach that the project describes are the potential to send an alert when a preservation action is required and to automatically identify a preservation action using the explicit preservation requirements of an organisation.

[96] This technology response type is sometimes referred to as technology trends. The Library and Information Technology Association (LITA) (item 1g on Annex 2) has been identifying significant trends for the community since 1999.

[97] Jones and Twiss identified monitoring as an essential technology forecasting technique. They strongly recommended conducting a continuous survey of the total environment – not just technology developments, but legislative, organisational, funding, industrial, and social developments. They noted that creating an iterative scanning process may identify potential substitutes for current technologies. Jones and Twiss, *Forecasting Technology*, 75, 80, 84, 92.

[98] Information was often gathered and processed manually. In rare cases, minimal automated means were used. Jones and Twiss, *Forecasting Technology*, 137-140.

[99] Coates, 'Boom Time in Forecasting', 37.

the Web to disseminate results coincided with a resurgence of interest and commitment to the technology monitoring approach.[100] The increased storage capacity and processing speeds of ordinary computers that made the spread of the Web possible have also made possible the intensive data processing needed to implement large-scale tracking of technology developments, which requires accessing a wide variety of information sources.[101] This new capacity also presents a challenge in that "the increasing availability of information about emerging technologies makes it ever more critical to recognize the importance of monitoring".[102]

The need for technology monitoring is recognised in many domains. For example, the Web site of one initiative states that "technology monitoring is seen as an increasingly essential input for decision making by policy makers and enterprise managers in the context of the rapidly changing industrial and technological scenario in the developing countries".[103] The Monitor Technology function description in the OAIS is the first formal reference to technology monitoring in the digital preservation community.[104] The function description in the OAIS Reference Model document states that the objective of Monitor Technology is to avoid obsolescence.[105]

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[100] Linstone, 'TFSC: 1969-1999', 2; Alan L. Porter, 'Technological Forecasting: An Empirical Perspective', *Technological Forecasting and Social Change* 62 (1999): 25-26; and Porter, 'Depth Perception', 143.

[101] This renewed interest based on increased capability produced a number of the technology watch examples included in the survey, although the origins of some of the technology watch examples predate both the Web and the Internet, as the starting date for a number of the examples described in Annex 2 indicates.

[102] Porter, 'Depth Perception', 143.

[103] The profile for the Technology Information, Forecasting & Assessment Council **(**TIFAC) Technology Watch in India item 2f in Annex 2.

[104] Section 1.5 on the extent of the response to technology in the digital preservation community introduced the Monitor Technology function in OAIS. The Monitor Technology function generates four types of outputs: reports, technology alerts, external data standards, and prototype results. The OAIS document provides no description of the reports or alerts that would be generated by the Monitor Technology function. Section 4.7 on the notify function of the technology response model considers reports and alerts for the digital preservation community.

[105] CCSDS, *OAIS Reference Model*, 4-13 – 4-14. The description of the Monitor Technology function includes a reference to 'prototyping', an optional capability of the function that is not further defined in the OAIS document. The description suggests that, if included, prototyping would provide active evaluation, analysis, and testing of emerging technologies. In addition to the description of the function, the Monitor Technology function is referred to by two other Preservation Planning functions, specifically *Develop Preservation Strategies and Standards* and *Develop Packaging Designs and Migration Plans* and is included in two OAIS diagrams, the diagram for Preservation Planning and the composite diagram of OAIS. CCSDS, *OAIS Reference Model*, 4-12 – 4-14; F-2.

The evaluation of technology monitoring as a technology response identified text mining as a means for implementing technology monitoring. This technique involves applying automated means to find, select, extract, process, and present relevant information in digital form.[106] One caveat authors on text mining noted is that computers cannot replace the human role in text mining; expert analysis is needed to develop and refine the application of the tools, interpret results, and highlight significant findings.[107] An objective of the text mining technique is to identify a "novel association" by analysing the information.[108] Text mining has origins in the use of historical resources for research and in longitudinal analysis.[109] The principles of and hopes for text mining were expressed by Vannevar Bush in his essay, "As We May Think", in 1945.[110] These authors suggest the need for accessing stores of technology-related information.

Text mining became viable and more common over the past decade through advancements in information technology, including computer speed and storage, the scale and scope of information dissemination made possible by the Web, greater access to journals, newspapers, and other sources in electronic form, and tools to gather and retrieve information. [111] Techniques related to text mining include data mining, database tomography, bibliometric analysis, and automated semantic processing.[112] Technology advancements enabled these techniques through a shift

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[106] One recommendation for providing technology watch functionality to small businesses that was identified in the investigation of technology monitoring (discussed in Section 3.5) has potential relevance for digital preservation. The authors propose providing a technology watch through the establishment of "intermediate centers" that are shared by small businesses. The intermediate centers would apply text mining in collecting information and providing specialised software for information analysis. This suggests potential for distributed information gathering and collaboration that might be a good fit for technology responsiveness for digital preservation. Jorge (Gorka) Izquierdo, and Sergio Larreina, 'Collective SME Approach to Technology Watch and Competitive Intelligence: The Role of Intermediate Centers', NEMIS Conference, Athens, Greece, October 24, 2004.

[107] For example, Martino, 'Review of Selected Recent Advances', 720.

[108] Porter, 'Depth Perception', 144-145.

[109] Mariano Nieto, 'From R&D Management to Knowledge management: An Overview of Studies of Innovation management', Technological Forecasting and Social Change 70 (2003): 155.

[110] Vannevar Bush, 'As We May Think', *The Atlantic Monthly*, July 1945.

[111] Authors noted barriers to achieving effective text mining prior to the 1990s, including reliance on available indexing prior to wide availability of full-text sources, the subjectivity imposed by indexers, the lack of access to grey literature, and delays in publishing. For example, M. Callon, J. Law, and A. Rip, 'Putting Texts in Their Place', in *Mapping the Dynamics of Science and Technology: Sociology of Science in the Real World* (London: The Macmillan Press, 1986), 221-230.

[112] Harold A. Linstone, 'From My Perspective – TF/TA [technological forecasting/assessment]: New Driving Forces' *Technological Forecasting and Social Change* 68 (2001): 310. A prolific proponent

from “elaborate” processing of small amounts of information to extensive processing of vast amounts of information.[113] A parallel thread is referred to as literature-based discovery on the Web.[114] An example from the digital preservation community demonstrated how aggregations of information, or collections, could be automatically created using clustering and focused Web-crawling.[115] These approaches suggest how technology developments of interest could be detected and tracked.

Proponents of technology forecasting noted that a challenge in implementing forecasting techniques is gathering sufficient information about technology developments, including the social, economic, political, and historical contexts to enable the various analyses the techniques require.[116] Monitoring and environmental scans are two approaches for gathering information to understand and to assess a particular issue or topic that are often also identified by technology forecasting techniques. Environmental scanning involves identifying relevant policies, standards, developments, and events pertaining to the selected topic or issue to determine the current status or situation.[117] Both monitoring and environmental scanning require the ability to seek and detect relevant information to enable understanding and analysis that techniques such as text mining provide.

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of text mining, Ron Kostoff, has been a contributor to one of the technology watch examples that was included in the survey, Technology Watch and Evaluation at the Office of Naval Research. His research discusses results of experiments he has conducted to demonstrate text mining and the techniques and process needed to enable broad text mining. His contributions include: Paul B. Losiewicz, Douglas W. Oard, and Ronald N. Kostoff, ‘Textual Data Mining to Support Science and Technology Management’, *Journal of Intelligent Information Systems* 15, no.2 (2000): 99-119; Ronald N. Kostoff,, ‘Stimulating Discovery’, *Discovery Science* (2001): 196-213; and R.N. Kostoff, ‘Text Mining for Global Technology Watch.’ In the *Encyclopedia of Library and Information Science* 4, M. Drake. Ed., 2nd Edition. (New York, NY: Marcel Dekker, Inc., 2003): 2789-2799.

[113] Porter refers to this ability ‘depth perception’. He recommends several community-based steps for achieving it, such as: recognising the increasingly accessible information on science and technology developments and providing continuing access to that information; developing analytical tools to recognise important changes and ferret out technical and socio-economic relationships; devising ways to represent critical relationships and their implications; awakening management to the value of such information. Porter, ‘Depth Perception’, 144.

[114] Michael Gordon, Robert K. Lindsay, and Weiguo Fan. ‘Literature-Based Discovery on the World Wide Web’, *ACM Transactions on Internet Technology* 2, no. 4 (2002): 261-275.

[115] Donna Bergmark, ‘Collection Synthesis’, *Proceedings of the 2nd ACM/IEEE-CS joint conference on Digital Libraries*, 253 – 262.

[116] Jones and Twiss, *Forecasting Technology*, 27.

[117] Jones and Twiss, *Forecasting Technology*, 137-140.

A technology watch is the most common technology response example and it is most often associated with technology monitoring.[118] The investigation of technology responses documented the fact that definitions of the term *technology watch* are not often provided.[119] This seems to be the case because the term is thought to be implicitly understood, although a technology watch may be provided in varying forms and, therefore, must vary in definition, depending on the context. The survey identified four categories of technology watch services: digital preservation examples; national and international technology watch initiatives; other domains: technology analysts; and other domains: industry-specific. The survey of technology watch examples demonstrated that a technology watch has no single interpretation, but at minimum a technology watch identifies and describes emerging technologies, usually for a specific audience. One example from the digital preservation community defines a technology watch in the context of the OAIS Reference Model. [120] The brief discussion of the technology watch function in this example recognised that providing the function is a digital preservation community concern. This example reflects several elements that are common to the digital preservation community's perspective towards a technology watch. The scope of existing technology watch examples for digital preservation generally consists of obsolescence concerns regarding software that created and provides access to digital content, sometimes including the software and hardware for repositories that manage digital content.

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[118] For example, the digital preservation examples listed in Section 1.5 typically demonstrate compliance with the monitor technology function of OAIS. See for example: Sierman, *Report on Comparison of Planets with OAIS* PLANETS.

[119] For example, in more than twenty references to technology watch identified in the ACM Transactions, none contained a definition of the term and only referred to the term or recommended that a technology watch function should be in place.

[120] One definition of a technology watch was identified in the digital preservation community. It is specific to the OAIS Reference Model and so does not lend itself to general use. In its second Technology Watch series report on institutional repositories, the Digital Preservation Coalition (DPC) defined a technology watch as a function that "monitors Representation Information and related rendering capabilities and provides alerts when the Representation Information is no longer current due to technology obsolescence". The DPC report acknowledged that the method for providing this technology watch function was not yet clear and that the function needed to be operated iteratively to maintain current information. The report noted that in addition to representation information, hardware and software that enable institutional repositories. Paul Wheatley, *Institutional Repositories in the Context of Digital Preservation*, DPC Technology Watch Report 04-02, 2004, 11. http://www.dpconline.org/graphics/reports/ Representation Information is the term used by the OAIS Reference Model to refer to the technical information that is stored in the Archival Information Package (AIP) to enable computers to present the digital content in the AIP to users. CCSDS, *OAIS Reference Model*, 1-13.

The investigation of technology monitoring included a survey of technology watch implementations to identify characteristics and approaches that could be adopted or adapted for the digital preservation community.[121] The sources surveyed included journals, bibliographies, reports, articles, conference proceedings, and Web sites that reference technology trends and technology watch products, services, and techniques. The survey reviewed a broad array of implementations that have been labelled or described as a technology watch.[122] In addition to digital preservation examples, the review of technology watch efforts identified examples in the domains of management and business, marketing, manufacturing, construction, information science, and computer science. The survey included seven digital preservation community technology watch examples, seven national and international initiatives examples, six technology analyst examples, and four industry-specific examples. The remainder of this section discusses the results of the technology watch survey. The discussion is organised into five themes that were identified during the survey: scope and services, collaboration, impartiality, transparency, and sustainability.

Scope and services: The scope of two national initiatives has potential utility for digital preservation. In 2001, the Joint Information Systems Committee (JISC) held a conference called the JISC Technology Watch Conference and since has requested and recommended reports on technology developments.[123] The Cyberinfrastructure Technology Watch is a science and technology initiative.[124] Both include the longevity of digital information as an issue.

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[121] Annex 2 provides profiles, e.g., the scope, purpose, and funding model, for the technology watch examples that were included in the survey.

[122] These technology watch efforts may be broad or narrow in the scope of technologies tracked, may be national or industry-based, may be government sponsored or private, and may serve academic or commercial purposes. The profiles of the technology watch examples included in the survey are provided in Annex 2.

[123] The *Standards and Technology Watch* (item 2b in Annex 2) provides an A-Z of topics, including some that are of direct interest to digital curators, e.g., digital rights management, but the technology watch provided by JISC does not express the intention of accumulating and providing access to these citations over time. The JISC funds digital preservation research, but the focus of this technology watch is not on digital preservation and the implications in the commissioned and published reports do not focus on preserving the digital content that the featured technologies produce.

[124] *Cyberinfrastructure Technology Watch* is an initiative of the US National Science Foundation (NSF) (Item 2a in Annex 2). One limitation of the NSF approach is that the organisers presume that long-term retention of digital content is a solely technological concern, overlooking the organisational context required to sustain digital preservation programmes.

The most common technology watch service identified in the survey is the generation of an annual report featuring one or more technologies with summary or detailed descriptions. These reports typically include one or more recommendations or observations about the potential implications of the technologies for the users.[125] These examples suggest components that might be included in a response to technological change for digital preservation. The survey of technology watch examples also suggests that users of the service have little or no access to the information the technology watch service used to compile the report.[126] This lack of access is significant in addressing the need to educate a community about technology developments.

Another aspect of scope and services is the audience for and purpose of the technology watch. The audience for the Office of Naval Research (ONR) Technology Watch and Evaluation is identified as science and technology "management decision aid disciplines".[127] The Canadian Heritage Information Network (CHIN) recommendation for a technology watch suggested that the technology watch should reflect the needs of digital curators. [128] The delivery of

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[125] One service that was not large enough to include in the survey, *NewsScan*, is an exception that offers a subscription to daily or weekly news about information technology in the form of brief digest. *NewsScan,* http://www.newscan.com/ (accessed 20 May 2008). For these technology watch examples, the annual report is often the only product provided by the technology watch.
[126] For the commercial technology watch services, the availability of and fee structures for consulting and other services from the technology watch provider suggests that providing the technology watch service may fuel consulting and other services. If so, that may provide an explanation for the lack of access to the information the provider accumulated to develop the technology watch reports. Aberdeen (item 3c in Annex 2) is a commercial technology watch service that appears to provide customised services based on the needs and interests of its users. The *Executive Perspectives: Technology Watch* from QinetiQ (item 3f in Annex 2) provides a fee-based service to develop case studies on technology developments in response to client needs. Outsell (item 3b in Annex 2) is one of the few technology watch examples that provides levels of services to users based on their needs, their resources, and their need for advanced information about technology developments.
[127] The *ONR Technology Watch* (item 2c in Annex 2) explicitly states that their technology watch integrates technology watch and technology evaluation, discussed with technology assessment in Section 3.3.
[128] The CHIN report was introduced in Section 1.2. The scope for a technology watch proposed by CHIN is limited to formats and media, but the products and services are the most explicit and extensive within the digital preservation community: "a comprehensive list of common and uncommon file formats including applications which can read, write and edit the formats; a comprehensive list of media types with handling recommendations for each type, vendors which manufacture the media and devices capable of reading the media; case studies on the migration of individual formats or medias to newer formats or media including specific techniques, possible informational loss and other risks associated in the conversion process; emulators for specific environments or contexts and current research; a list of institutions with specific expertise on a format or media type so that institutions could contact them with specific questions; timely

technology watch products and services the CHIN report describes would be disseminated to users, but the report suggests that users should also participate to influence the direction and content of the technology watch. The services typically offered by the technology watch examples suggest that the primary purpose is to raise awareness and inform the intended audience about technology developments. The services often do not include recommendations for the development of a response to technology developments.

Collaboration: The examples suggest opportunities for collaboration in developing technology responsiveness for digital preservation. A geospatial technology watch provided an example of a technology watch from another domain that might offer the opportunity to exchange information about technology developments of interest.[129] Developing digital preservation strategies relies upon this kind of information about specific digital content types. It should be more cost-effective for communities to exchange technology monitoring information rather than separately accumulating all of the information of interest. The JISC Technology and Standards Watch is another example that could contribute specialised information of interest for digital preservation through collaborative efforts.[130] The JTC Technology Watch project defines their scope of the technology watch more broadly than the digital preservation community examples, but the scope of the JTC initiative intersects with the digital preservation objectives and may offer opportunities for collaboration.[131] Gartner Research is a commercial effort with a significant academic focus and base.[132] The digital preservation community could learn from the Gartner approach and there may be the potential for partnering on technology responsiveness, e.g., the digital preservation

dispatches warning institutions when a particular format or media type may be in jeopardy; and general technology events that may have a long term impact". Au Yeung, *Digital Preservation for Museums*, 18.

[129] *GiMoDig* is a shortened form of 'Geospatial info-Mobility service by real-time Data-Integration and Generalisation' (item 2g in Annex 2).

[130] The *Technology and Standards Watch* is a service of JISC (item 2b in Annex 2).

[131] The JTC 1 working group explains the rationale for the group by acknowledging that ICT continually evolves and noting the JTV scope of interest is broader than their existing work groups so the technology watch would enable them to monitor technology beyond their activities. Coallier, 'JTC 1 Technology Watch'.

[132] Gartner (item 3a in Annex 2) does not identify itself as a technology watch, but it sorts high on search engine results for 'technology watch' and it provides information and services that classify it as a technology watch. They have been conducting research on technology developments for more than twenty-five years.

community could provide updates and information pertaining to digital preservation that might be of interest to Gartner's broader audience. The digital preservation community could build on, refer to, contribute to, and partner with other technology watch and technology trend efforts.[133] Collaboration may be a key to developing and sustaining a response to technology for digital preservation.

Impartiality: Providing impartial information about technology developments is important to ensure that recommendations about technology developments are not influenced by potential financial gain through wider use of technologies. The PRONOM Web site acknowledges this need in stating that "PRONOM is a resource for anyone requiring impartial and definitive information about the file formats, software products and other technical components required to support long-term access to electronic records and other digital objects of cultural, historical or business value". DigiCULT provides another example: "The *DigiCULT Technology Watch Report* is a major annual volume, covering six technologies expected to have a substantial impact on the future of cultural heritage projects, professionals working in the sector, and approaches to cultural materials. Their primary aim is to give a solid and impartial grounding in new and developing technologies to those without the time or the IT confidence to gain an independent familiarity, together with a view of the changing technological and methodological landscapes".[134] The DigiCULT site echoes PRONOM's reference to impartial information as a feature of their service, which is free. It also notes the lack of time and lack of technical confidence as motivating factors for users of the service. These are important considerations in developing technology responsiveness for digital preservation. Sometimes the best or only source of information about a technology development is the developer or the agent for purchasing the technology, making a determination of the accuracy and impartiality of the information difficult.

[133] Some categories of technology developments that contribute to information technology advancements might be more appropriately tracked by other communities. Examples include advancements in the characteristics of physical materials used to build computers and enhancements to the infrastructure needed for power delivery and telecommunications. These examples might be tracked by the engineering and telecommunications domains using skills developed to understand and interpret the significance of technology developments.
[134] *DigiCULT Technology Watch Reports* are listed as item 1d in Annex 2.

Transparency: Many technology watch examples lack transparency about the methodology used or the sources gathered to produce the technology watch reports. Each technology watch report example features several emerging technologies, but the criteria used to identify the technologies to feature are often not identified. There are typically no indicators that the selection is systematic, representative of the expressed interests of users, or influenced by the evolving needs of users.[135] As previously mentioned, for commercial examples the lack of transparency may be attributed to the monetary value of the information as a paid service to users. The promotional materials for several of the commercial technology watch services highlight lists of emerging technologies reviewed as part of the packaging for the technology watch service. This suggests that there may be little incentive for technology watch services to be transparent about sources and methods that might enable users to engage in their own investigations, especially when the services are fee-based. Although the technology watch may be trusted, the technology response for digital preservation will require transparency to document the rationale for preservation strategies and other decisions that may be based on the results of a technology watch.

Sustainability: Most of the technology watch examples surveyed are still available online, but some are no longer active, i.e., monitoring of technology developments has ceased and no reports or updates are being generated about current developments. [136] An inactive technology watch implementation may be an indication that the service provided by the technology watch is not responsive to the community or the community does not see adequate value in the technology watch to sustain it. It will be important for the digital preservation community to identify incentives for contributors to and users of any implementation that intends to enable

[135] One exception is the *DigiCULT Technology Watch Reports* (item 1d in Annex 2) that do identify the convening of an expert panel as the method for the selection of technologies that are discussed in the reports.

[136] The ‘SeniorWatch’, a European technology watch for products and services for older or older disabled people, was ended after three years of funding from the ’Information Society Technology’ programme of the European Community. ‘European SeniorWatch Observatory and Inventory’, http://www.seniorwatch.de/ (accessed 20 May 2008). DigiCULT Technology Watch Reports (item 1d in Annex 2) are no longer being produced, although the three annual reports DigiCULT completed are still available; and the funding for the GiMoDig Technology Watch project (item 2g in Annex 2) ended. The Future Lines of User Interface Decision Support (FLUIDS) Technology Watch was not included in the survey because it had so clearly been abandoned. ‘Future Lines of User Interface Decision Support (FLUIDS) Technology Watch’, http://www.dfki.de/fluids/Technology_Watch_Activity.html (accessed 20 May 2008).

a comprehensive technology response for digital preservation. Being responsive to technology developments over time will require sustained support. Sustainability may also require an institutional base, but community support will be essential.

To conclude, most of the technology watch examples offer users little opportunity to control or influence the selection of topics or the direction of technology tracking. The digital preservation community needs to be able to identify technology developments that are most relevant for digital preservation and to set priorities for delving deeper into selected topics. Most of the technology watch examples provide users with little or no access to the data and information the developers of technology watch reports and products accumulated to produce reports and updates. Only a few of the technology watch examples provide levels of service or the ability to customise products or services, and most of the examples that do provide these flexible services are offered by commercial providers that charge substantial fees. Flexibility is important because digital preservation planners and curators have a deep understanding of some kinds of technologies and very little about other kinds. Technology watch reports may include an analysis of the potential implications of selected technology developments, but many simply describe and explain technology developments; evaluation may be offered as an additional service. The services offered by the technology watch examples may enable responders to develop a suitable response to the technology development, but procedures and techniques for developing a response are not explicit components of technology watch examples. Some technology watch examples offer training that might enable the development of a response to technology developments of interest.

The survey of technology watch examples further confirmed that the digital preservation community tends to focus on file format and storage media obsolescence issues rather than the full spectrum of technology developments that might be considered.[137] Technology watch examples that focus on the information

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[137] The digital preservation examples also often limit their scope to developments that have occurred within the digital preservation community, rather than broadening the scope of their scans to include technology developments in whatever domains the developments occur. For example: *Preserving Access to Digital Information (PADI)*, National Library of Australia (item 1c on Annex 2) and the

technology domain may be the most relevant for digital preservation because these examples show a significant overlap in technology interests and often share similar objectives. The business-related, commercially operated, and industry-based examples offer a range of possible services, products, and funding models, but adopting or adapting those approaches would require addressing the fee-for-service approach that might not fit the resources available to the digital preservation community.

With the exception of the recommendations in the CHIN report, there is no formal, common, or even explicit definition of the expected scope, purpose, products, or services of a technology watch. This lack may be addressed by an international technology watch standard that was identified during the investigation of technology monitoring and technology watch examples. This standards development effort is a project of the Joint Technical Committee on Information Technology Standardization (JTC 1) Special Working Group on Technology Watch.[138] The intent of the JTC 1 technology watch initiative is to provide annual internal technology watch reports.[139] The terms of reference for the group are available, as well as fairly detailed descriptions of the intended deliverables from the project team.[140] This is the first example of an effort to standardise a technology

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Berkeley Digital Library SunSITE) (item 1f on Annex 2). Technologies of potential interest for digital preservation are discussed in Section 2.6

[138] JTC 1 is a committee of the International Standards Organization (ISO) and International Electrotechnical Commission (IEC). JTC members are national standards bodies. JTC began working on the technology watch project in 2002. JTC 1 is working on a proposed standard taxonomy for information and communications technology (ICT) that was referenced in the discussion of categories of technology developments of interest for digital preservation in Section 2.5. Coallier, 'JTC 1 Technology Watch'.

[139] JTC 1 is proposing a standard template for technology watch reports with five common sections: an executive summary that synthesises the results; a version control section; the scope and purpose of the report; an overview of technology drivers for the technology developments discussed in the report, e.g., technology developments, and market changes; and an intensive technology forecast pertinent to the JTC context. The forecast report is referenced in Section 3.2 on technology forecasting. These reports are intended to support JTC 1 business planning. JTC needs comprehensive assessments to inform their business decisions about technology infrastructure and investment directions. Coallier, 'JTC 1 Technology Watch'.

[140] The results of the group are not completed and may remain accessible only to the JTC committees. This is a high-level, internal development for the IT standards community. No additional information is available from the group. There were no published sources of information about the initiative apart from the information made available on the project Web site as of October 2007. This initiative has not yet provided technology watch examples, so the effort is not included in the list of examples in Annex 2 because there were no content or services to evaluate. If the JTC group produces a standard for an annual technology report and shares their model for their annual technology watch cycle, those developments may be useful to the digital preservation community and have some influence on communities that are interested in technology responsiveness.

response, and the resulting standard is one that the digital preservation community could adapt.

A second result of the survey of technology watch examples was the identification of indicators that illustrate the broad use and impact of technology watch functionality across domains. These indicators include references to a technology watch in information sharing, career advice, job descriptions, and work plan milestones.[141] These additional examples are indicators of the degree of acceptance and increasing reliance on technology watch functionality. The survey identified features, characteristics, and issues to consider in developing technology responsiveness approach for digital preservation.

3.6 The Human Factor in Technological Change

So far this chapter has addressed four specific types of responses to technology developments. This section addresses the more general human response to technological change. This is significant for the investigation of technology responses because the innovation and diffusion stages of the innovation cycle rely upon humans to develop the requisite knowledge and skills to use technology developments.[142] If technology developments are not widely diffused, the impact of those developments is limited and quantitatively less significant.[143]

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[141] For information sharing, there is a technology watch blog that promises to "keep an eye on what's news in tech". *ITProPortal.com*, http://blog.itproportal.com/ (accessed 20 May 2008). The archive section of the blog contains content beginning in October 2005. *The Economist* magazine provides a more formal example of information sharing with quarterly updates on technology. '*The Economist* Technology Quarterly', http://www.economist.com/science/tq/ (accessed 20 May 2008). For career advice, a popular job hunting Web site for information technology professionals used a technology watch feature to identify top technologies to track for career development and job hunting. 'Monster Career Advice – Technology', http://career-advice.monster.com/technology-skills/technology/home.aspx (accessed 20 May 2008). For job descriptions, the Ohio Supercomputer Center (OSC) posted a Computational Scientist position that required to provide "a technology watch function for program team". The Ohio Supercomputer Center (OSC), http://www.osc.edu/aboutOSC/jobs.html (posted January 28 to February 12, 2006). For strategic actions, a list of 'Must Do' Milestones for a knowledge management strategic plan included involvement in a national forum on technology watch. University of Edinburgh, 'Knowledge Management 2004-2005 Strategic Plan', http://www.kmstrategy.ed.ac.uk/Must_Do_Milestones.htm (accessed 20 May 2008).

[142] Thomson, *Learning and Technological Change*, 1-3; and A.S. Bhalla, and James Dilmus, 'New Technologies and Development: Experiences', in *Technology Blending*, (London: Lynne Rienner Publishers, 1988), 43, 45. Section 2.3 introduced and discussed the innovation cycle for technology.

[143] For digital preservation, the ideal would be to detect, monitor, and respond to technology developments that will have the greatest impact on preserving digital content based on the extent of

The complexity of technology and an associated lack of broad understanding of technologies can be barriers to the diffusion of technology because as the complexity of technology increases, the understanding of the technology increasingly becomes the domain of experts.[144] An example from history illustrates this point. The hearth was an accessible technology for average people for centuries, but an understanding of the operation of the furnace, adapted from the hearth for heat production, is the domain of trained experts.[145] Diffusion of an emerging technology may require both the emergence of experts who are skilled in the implementation of the technology and the spread of a basic understanding for using the technology along with a willingness to do so. The digital preservation community has recognised and is taking tangible steps to address the need to continually learn about and respond to new technologies and to devise the most appropriate curriculum and vehicles for training and education.[146]

The human element of technology diffusion was described and formalised in 1962 by Everett Rogers.[147] He developed an often-cited model defining the characteristics of the stages and roles for the adoption of new technologies that is summarised in Figure 3-1.[148] The roles described by Rogers target the diffusion stage of the innovation cycle.[149] The technology adoption roles are also significant for digital preservation in two ways. First, the stages of technology adoption are

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digital content or the significance of the digital content that relies upon the technology development, as discussed in Section 2.3.

[144] Buchanan, *The Power of the Machines*, 224-225.

[145] Stanley R. Carpenter, 'A Discussion', *Philosophy and Technology*, Paul T. Durbin, and Friedrich Rapp, eds., 1983 (Dordrecht: Reidel, 1983), 1-12.

[146] Walch, 'Innovation Diffusion', 506-512. Curriculum examples pertaining to the digital preservation community include, the Digital Curation Curriculum project at UNC Chapel Hill, 2006-2009 and the Data Curation Education Program (DCEP) at UIUC, both of that address the skills needed by curators. Digital Curation Curriculum (DigCCurr) Project, http://www.ils.unc.edu/digccurr2007/ (accessed 25 May 2008); and Data Curation Education Program (DCEP), 'Master of Science--Concentration in Data Curation', University of Illinois at Urbana-Champaign, http://www.lis.uiuc.edu/programs/ms/data_curation.html (accessed 25 May 2008).

[147] Everett Rogers, *Diffusion of Innovations*, 4th ed, (New York, NY: Free Press, 1995).

[148] For example, Buchanan, *The Power of the Machines*, 22, Pederson, 'Empowering Archival Effectiveness' 430-453, Floridi, *Philosophy and Computing*, 56-61. and Yourdon, *Decline and Fall of the American Programmer*, 117.

[149] The innovation cycle was introduced in Section 2.3. *Innovators* and *early adopters* initiate the adoption of an emerging technology. *Popularisers* and *followers* bring the use of an emerging technology to a critical mass. A strong reluctance by conservatives and resistors to move away from an existing technology, if those groups are large and influential enough, can prevent new technology from flourishing. See for example the discussion in: Yourdan, *Decline and Fall of the American Programmer*, 117.

influential in determining the potential impact of an information technology development for digital preservation. Monitoring for indicators of technology acceptance, e.g., an increase in the number of products that rely on or use the technology development, might inform projections about the impact of technology developments. Second, digital curators also display the characteristics of the roles in responding to technology developments and in the development of digital preservation strategies that address the requirements and characteristics of information technology developments.

Stages	**Roles**
Pioneer	Innovator
Early expansion	Early adopters
Takeoff	Popularisers
Bandwagon	Followers
Late	Conservatives
Terminal	Resistors

Figure 3-1. Rogers' technology adoption model.

The development of technological competencies is such an inherent part of technology development that competencies form a distinct category in technological literature. Meiler Puge-Jones defined seven levels of technical expertise that can be used by organisations or by individuals to delineate and develop competencies. [150] This perspective focuses on the competencies needed to perform the roles that Rogers' model defines. These levels suggest the range of basic to advanced information that will be needed for technology responsiveness to meet the varying needs of digital curators.

[150] These levels were originally defined for software engineers, but could be applied to the competencies required by digital curators. Level one, an *innocent*, has never heard of the technology. Level two is *aware* of the technology based upon reading an article or two. Level three, an *apprentice*, may have attended a seminar on the technology. Level four, the *practitioner*, is ready to use the technology. Level five, the *journeyman*, uses the technology naturally and automatically. Level six, the *master*, has internalised the knowledge of the technology. Level seven, the *expert*, can teach others about the technology and may extend the technology in some way. Yourdan, *Decline and Fall of the American Programmer*, 61.

Learning to use an emerging technology is a type of innovation that requires some level of creativity.[151] The Rogers model addresses the learning curve necessary to understand new technologies and the acceptance levels by organisations and individuals required for adoption of a successful technology development.[152] As individuals or as a group, digital curators may be either receptive to or resistant towards new approaches and technologies. The acceptance of new technologies and the need to continually build competencies to be able to use and understand new technologies are just a couple of the human factors that have to be addressed in developing technology responsiveness for digital preservation.

3.7 Combining Technology Responses for Digital Preservation

Each of the four types of technology response has specific objectives and desired outcomes.[153] The introduction to this chapter noted that discussion of these technology responses is sparse in the literature of the digital preservation community.[154] The investigation of the four technology response types demonstrated that the technology response types are not synthesised in the literature of any domain.[155] This lack of integrated discussion may be due to the focus of each response type on producing specific results that do not require a consideration of the other response types. This section first considers the strengths of each technology response type and then considers the potential benefits of bringing

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[151] Tenner noted that the development of "technique is crucial for the evolution of technology". Edward Tenner, *Our Own Devices: How Technology Remakes Humanity*, (New York, NY: Vintage Books, 2004), 28.

[152] In 1993, the Society of American Archivists (SAA) Committee on Automated Records and Techniques (CART) report on the CART Curriculum Development project cited the Rogers model. The authors of that SAA report equated the stages of adopting technology to the stages for developing the skills needed to understand and use technology. Walch, 'Innovation Diffusion', 510. In 1995, Ann Pederson reviewed the role of David Bearman as an innovator in recordkeeping. Pederson, 'Empowering Archival Effectiveness: Archival Strategies as Innovation'.

[153] Technology forecasting is intended to predict the path and speed of technology developments to enable the exploitation of the potential of technology developments for financial and other gains. Technology assessment is intended to prevent negative impacts of technology developments by identifying potential implications and recommending actions to avoid damaging outcomes. Technology transfer makes use of technology developments from other domains through adaptation or adoption. Technology monitoring is intended to raise awareness about technology developments, typically within a specific community context.

[154] The discussions of the technology response types in Sections 3.2 through 3.5 identify examples from the digital preservation community.

[155] The discussion of the technology response types noted overlaps between the response types. For example, technology monitoring is identified as a technology forecasting technique.

together the techniques, results, and features of the technology response types. The objective is to integrate the cumulative potential of the four types to develop a comprehensive approach for achieving technology responsiveness for digital preservation.

Technology forecasting gathers information and analyses it to provide an understanding of technology developments that enables the identification of opportunities offered by emerging technologies. The objective of technology forecasting is to advise more than to inform or educate. Technology forecasting identifies the potential opportunities of technology developments. The objectives of technology forecasting align well with those of digital preservation, perhaps with better results than when applied in the business domain in which it emerged. This is so because digital preservation does not rely upon cutting edge technology that can be difficult to accurately predict. However, like the business community, the digital preservation community cannot afford to make bad investments on potential technologies for preservation. Technology developments are likely to be of interest for digital preservation longer than for many businesses, allowing trends to develop. The digital preservation community can afford to take a longer view on technology developments, a perspective that fits with longitudinal technology forecasting techniques. A difficulty encountered in early technology forecasting is that faulty predictions can be too costly.

The technology assessment response was developed and refined to enable communities to weigh the implications of technology developments and to act to avoid potentially harmful repercussions of those developments. The primary result of a technology assessment is a set of recommendations for a suitable response to a technology development. Technology assessment requires the specification of the procedures and techniques used to produce the recommendations. An assessment begins after technology developments have been identified as having potential implications for a community. Apart from implementing the response, technology assessment may be the most important of the technology response types for digital preservation because it enables a response to technology and its primary objective is avoiding harm, both of which are essential for digital preservation.

The objective of technology transfer is to enable reuse of the results of research and innovation across domains, possibly in ways that were not intended by the developers. The survey of technology transfer examples suggests that digital preservation could benefit by identifying possible donors of relevant technology from communities whose actions demonstrate an interest in long-term access to digital content. There might also be an opportunity to spread good digital preservation practice and techniques to communities that have digital content of value. The digital preservation community has acknowledged the benefits of adapting approaches from other fields and even recommended using analogies.[156]

Technology transfer requires the skills to adopt, adapt, or develop selected technology developments. For information technology, the skills required for technology transfer are primarily in programming areas, but project management, marketing, and other skills may be needed. The technology transfer process produces lessons learned from the successes and failures of the process. Research and development can be extremely costly and digital preservation cannot afford to do all of the necessary work on its own. Technology transfer may reduce or remove development costs for digital preservation. Technology transfer has not been employed systematically for digital preservation. The digital preservation community has tended to look towards other information professions for compatible ideas and activities that might be useful.[157] A broader scan for useful practices may identify potential candidates for technology transfer, e.g., policies, procedures, tools, standards.

A primary purpose of technology monitoring is to ensure that a community is aware of technology developments that might pertain to its interests, and often to contribute to the development of an understanding of specific technology developments. Technology monitoring is often implemented as a technology watch; indeed, the investigation of technology responses concluded that for most communities a technology watch is currently the most common and tangible response to technology. Technology monitoring may enable one or more of the

[156] Stielow, 'Archival Theory Redux and Redeemed', 14-26; and Hedstrom, 'Understanding Electronic Incunabula', 340-341.
[157] This tendency was documented in the literature review in Section 1.6.

other technology responses but a comprehensive response will require more than monitoring and raising awareness; it will require informed and sustained action in response to change.[158]

The technology response types are distinct yet complementary. Figure 3-2 consolidates results from the investigation of technology responses to represent the relationships between the four technology response types. Technology monitoring, often implemented as a technology watch, is the foundation response that contributes to all of the other technology response types by enabling the detection of technology developments of interest. The results of all four types contribute to competency building, a core human factor in responding to technology.

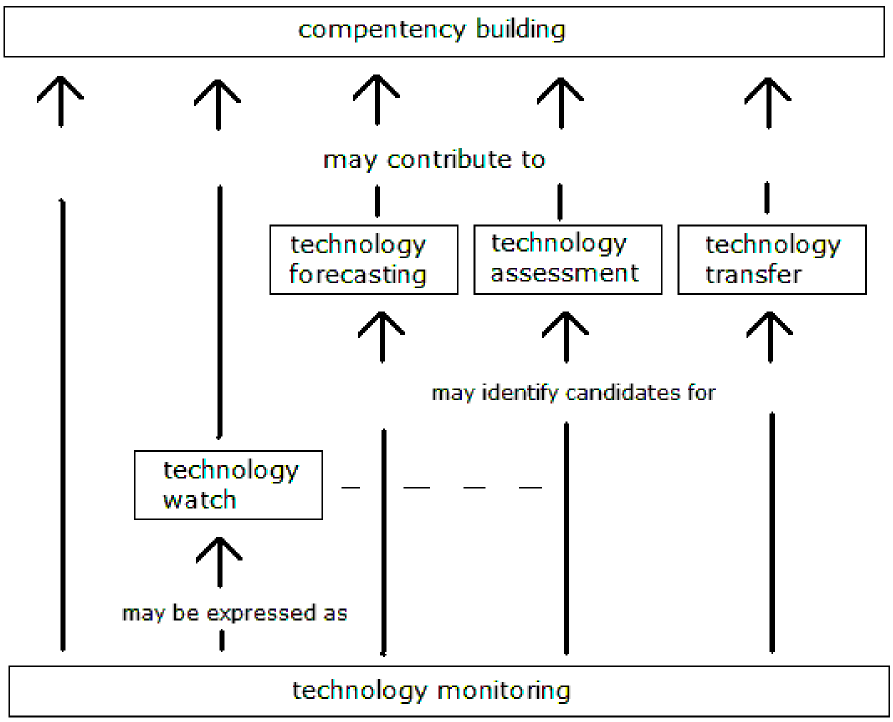

Figure 3-2. Relationships between the technology response types.[159]

This investigation into technology responses identified useful examples for digital preservation, and the review of the strengths of each technology response type suggests that no single technology response type is sufficient for achieving a

[158] For example, the TIFAC Technology Watch (item 2f in Annex 2) states that the approach incorporates technology assessment, technology transfer, and technology forecasting.
[159] The diagram in Figure 3-2 was developed by the author of this thesis to illustrate results from the technology response investigation.

comprehensive response to technological change. Technology monitoring promotes awareness. Awareness of potentially relevant technology developments is the starting point for the other three technology response types. Technology forecasting identifies opportunities and threats posed by technology to take advantage of the possibilities and to predict the probable development path of technology developments. Technology assessment provides recommendations to prevent potential harm as a result of technology developments. Technology transfer provides a means for adapting technology developments to develop or enhance capabilities in other domains. The intended outcomes of the four technology response types are awareness, exploitation, prevention, and adaptation.

3.8 Conclusion

The investigation of technology responses identified four response types, technology forecasting, technology assessment, technology transfer, and technology monitoring. To integrate the responses for application to technology responsiveness for digital preservation, the research characterised the outcomes of each of the four technology response types. The intended outcome of technology forecasting is the exploitation of technology developments for profit and progress. The intended outcome of technology assessment is the prevention of harmful impacts of technology developments. The intended outcome of technology transfer is adaptation to enable reuse of technology developments from one context to another. The intended outcome of technology monitoring is awareness and understanding.

The investigation documented that the awareness response mostly takes the form of a technology watch, apart from increasing discussions about and examples of text mining outside the digital preservation community to enable technology monitoring. Although the literature of the other three responses includes examples of national and international journals for each, there are far fewer transparent implemented examples of those responses. The review of the four technology response types determined that although the literature for most of the technology response types is extensive, the literature for each technology response type contains few references to the other technology response types. There is some inclusion of technology monitoring techniques and results in each of the other three technology responses. There were few examples of combining the technology responses and no examples that combined all four technology response types. The research identified no comprehensive or systematic attempts to consider the whole range of technology responses within the literature or extant practice of any domain.

Although the need for the digital preservation community to respond to technological change has been recognised, the means to achieve technology responsiveness is in the early stages of development. The digital preservation community's response to date could be characterised as aimed at prevention and resulting in limited awareness. The technology response investigation demonstrated that awareness and prevention are more familiar technology responses within the digital preservation community than exploitation and adaptation. There is potential for expanding both of these outcomes and incorporating exploitation and adaptation in more systematic ways, as well. Digital preservation literature does not typically or explicitly discuss efforts to exploit the potential of technology or to adapt the developments from other domains for digital preservation purposes. The exploitation and adaptation responses have been largely unexplored by the digital preservation community. The investigation of technology responses concluded that all four outcomes are needed to achieve technology responsiveness for digital preservation. The discussion of the extent of response to technology by the digital preservation community in Section 1.5, the literature review in Section 1.7, and the results of the investigation of technology responses confirm that none of the four technology responses has been systematically or comprehensively applied to digital preservation. [160] The research also showed that there are instances of technology responses within the digital preservation community and in other communities upon which to build.

The investigation of technology responses concluded that a combination of the four types of responses would be most effective for technology responsiveness

[160] For example, a search of the full-text version of the *American Archivist* 2000-2007, available from the Society of American Archivists, identified no references to any of the technology response types, although there were some references to technology in general. Society of American Archivists, 'Welcome to the American Archivist Online!', http://archivists.metapress.com/home/main.mpx (accessed 25 May 2008).

for digital preservation. These are possible applications of the technology responses to digital preservation. Awareness in the form of technology monitoring using the scope of interest in technology developments defined in Chapter 2 would provide the capability to inform the digital preservation community about relevant technology developments for digital preservation and serves as the basis for the other three technology response types. Existing technology response examples for digital preservation emphasise prevention and the need to avoid obsolescence of technologies upon which digital content relies, primarily represented by file formats with associated software and storage media. Technology assessment provides a means to formalise and extend the fundamental intent of the digital preservation community to prevent the loss of digital content. Exploitation as a response to technology, to emphasise the strengths and benefits of technology developments, highlights the incentives to identify the positive as well as the negative implications of technology developments for digital preservation during technology assessments. Technology forecasting techniques could be adapted for use in developing digital preservation strategies to enable the exploitation of the potential benefits of technology developments. Adaptation is a practical response to technology in the form of technology transfer that the digital preservation community could incorporate in the form of technology examples, collaborative research projects, or the development of prototypes. Each of the technology response types contributes to technology responsiveness for digital preservation.

Ongoing technological change offers potential opportunities and challenges to the digital preservation community for preserving digital content. Technological change presents a digital preservation challenge in the form of potential obsolescence of core technologies that directly generate and manage digital content. Technological change also offers opportunities in the development of new digital content and potential improvements of supporting technologies that enable essential digital preservation processes and practices. One objective for the digital preservation community could be to achieve a balance between avoiding the negative implications of technology developments, most often equated with impending obsolescence of technologies that support digital content stored as file formats, and maximising the potential benefits of new capabilities and attributes offered by technology developments.

Chapter 4. Technology Response Model for Digital Preservation

4.1 Introduction

In defining a technology response model for digital preservation, this chapter builds on and brings together the investigations of technological change discussed in Chapter 2 and the research on technology responses discussed in Chapter 3. The chapter characterises technology responsiveness for digital preservation as derived from the research findings. The technology response model for digital preservation includes a functional model with a discussion of each functional stage identified and a content model to characterise the information captured to achieve technology responsiveness for digital preservation. The model reflects an iterative approach to studying technology developments for digital preservation through the continual accumulation of information about technology developments and about ongoing technology assessments to promote a better understanding of the landscape of technological change as technology evolves.

4.2 Combining the Technology and Response Results

Technology responsiveness for a community addresses a relevant scope of interest in technology developments. Chapter 2 discussed the results of the investigation of technological change to identify the scope of interest in technology developments for digital preservation. In addition to identifying the characteristics of technological change and the cycle of technological change expressed by the innovation cycle, the outcomes of that investigation included a high-level technology framework of developments pertinent to digital preservation, an inventory of technologies that are potentially relevant for digital preservation, and a process for prioritising technology developments that might be detected as potentially relevant for digital preservation. The framework identified seven categories of technology-related developments: the object, collection, repository, platform, organisation, standards, and required competencies for the context in which digital content is managed. The technology inventory consisting of thirty-eight technologies and technological capabilities was developed through an analysis of technologies and technological capabilities required by the thirty-three functions defined in the OAIS Reference Model. The three-step process for prioritising potentially relevant technology developments included the definition of five priority criteria and three roles that an OAIS function plays in digital preservation (direct, enabling, and indirect), priorities assigned to OAIS functions based on the application of the priority criteria and the definition of roles, and the prioritisation of the technologies on the inventory by association of technologies to prioritised OAIS functions. The combination of these results provides the means to detect, prioritise, and monitor technology developments relevant for digital preservation. The technological change investigation also identified and evaluated information sources about technology developments.

The investigation of technology response types identified four technology response types (technology forecasting, technology assessment, technology transfer, and technology monitoring) and four associated outcomes (awareness, exploitation, prevention, and adaptation). Technology monitoring provides awareness and the starting point for the other three response types. Technology assessment enables prevention by identifying potentially negative implications of technology developments, a primary objective of technology assessments for digital preservation. Technology forecasting encourages the exploitation of positive implications of technology developments. Technology transfer supports the adaptation of technology developments for digital preservation. The technology response investigation also discussed that the human response to technology requires continual learning and competency building. The investigation concluded that technology responsiveness requires a combination of the four response types, and the technology response model for digital preservation reflects the strengths and intents of all four technology response types.

The innovation cycle provided a means for demonstrating how the results of the technological change and the technology response investigations were combined to provide the starting point for the development of the technology response model for digital preservation.[1] The process of combining the technological change and technology response results produced the technology

[1] The innovation cycle was introduced in Section 2.3.

response cycle for digital preservation, as illustrated in Figure 4-1.[2] The mapping suggests the points in the innovation cycle when the technology responses should be applied and which technology development techniques would enable the technology responses.[3]

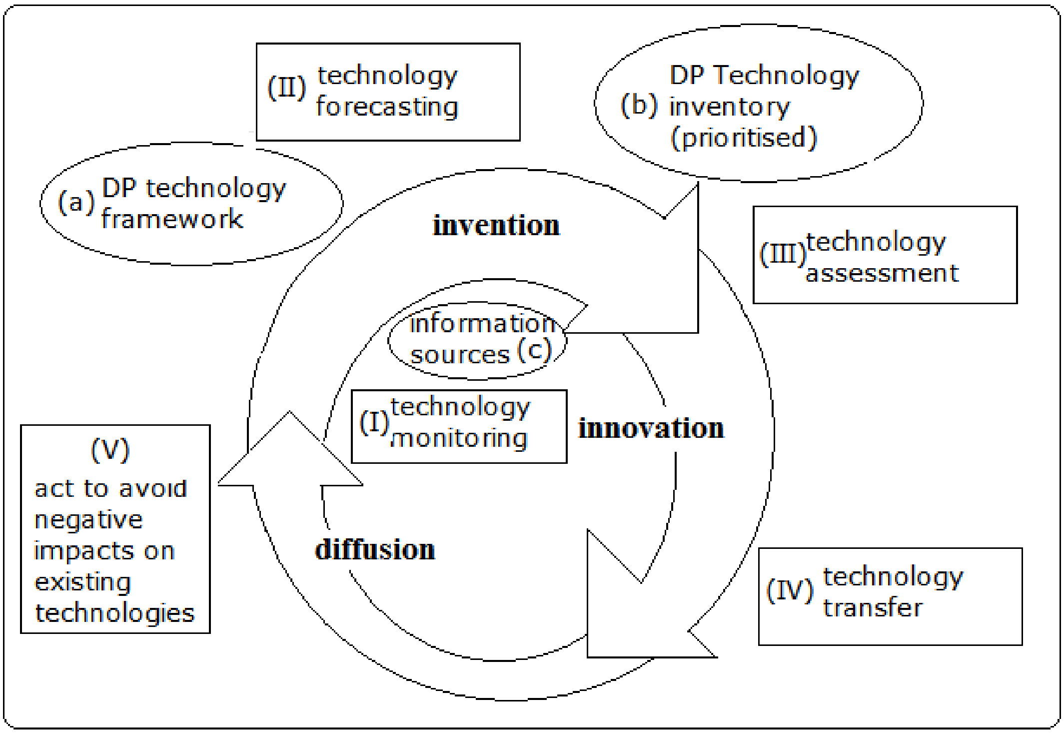

Figure 4-1. Technology response mapping for digital preservation.

Technology monitoring (I) is continual and harvests the broadest possible range of information sources (c). Technology forecasting (II) exploratory techniques would be applied to identify technology developments that are emerging – invented, but not proven yet – to suggest technology developments using the technology framework (a) and informed by the prioritised list of technology developments (b). Technology assessment (III) would utilise the prioritised list of technology developments (b) to select candidates for technology assessment.

[2] The innovation cycle illustrates the phases of development for a technology development. In Figure 4-1, the author of this thesis mapped the technological change and technology response results to the diagram of the classic innovation cycle that was adapted for use in Figure 2-1 in Section 2.3 on technology innovation.

[3] One characterisation of the ideal cycle for responding to technological change identified early detection or anticipation, evaluation, and action and suggested that the objective of responding to technology should be to consider the range of possible technologies rather than select one. This perspective aligns with the objectives of technology responsiveness for digital preservation and assisted with the placement of the technology responses in the diagram. Bauer, et al, *Second Order Consequences*, 27-29.

Normative technology forecasting techniques would also be used to project the potential impacts of technology developments during a technology assessment. Technology assessment (III) would occur when technology developments are proven but not yet widely disseminated. Suggestions for technology transfer (IV) candidates might be an outcome of technology assessments.

The technology response “act to avoid negative impacts on existing technologies” (V) was added to the diagram during this mapping of the technological change and technology responses results. This response represents a specific form of the prevention (technology assessment) response that is known to the digital preservation community, most commonly in the form of avoiding obsolescence of file formats and which, in that form, has largely been addressed. The investigation of technological change noted that technology developments may lead to the displacement of existing technologies. A technology assessment would determine the implications of an emerging technology for digital preservation as well as for existing technologies. As soon as monitoring detects indicators that an effort is being made to replace or enhance an existing technology, preparations should begin to avoid the impacts of obsolescence due to superseded technologies.

As noted in the discussion of the innovation cycle in Section 2.3, the technology innovation cycle focuses conceptually on one technology development at a time, while technological change occurs through complex interactions of cumulative technology developments. Therefore, the continual scan of technology developments would include tracking many developments simultaneously and the technology response cycle for digital preservation would be applied concurrently to technology developments. This layering of activities is the basis of comprehensive monitoring, assessment, and response for digital preservation.

This is the scenario envisioned for the technology response cycle for digital preservation as it wraps around the technology innovation cycle. The process begins with monitoring of technology developments using the inventory of technologies for digital preservation as a starting point. Continual monitoring would detect indicators of technology developments that have potential implications for digital preservation during the invention stage of an emerging technology. Indicators of an invention might be a vendor announcement, a research report, or increasingly an entry in a technology-related Web blog.[4] Once a technology development of potential interest is identified, monitoring would search for indicators that the technology development is shifting from the invention to the innovation stage. Indicators of this shift might include a press release, an announcement, an article in a technical journal, a presentation at a conference, or a technical report. When that shift is detected, the information technology development would be nominated to the digital preservation community for the completion of a technology assessment. The technology assessment would provide recommendations for digital preservation community response to the technology. One recommendation might be that the technology development could be adapted for use by the digital preservation community. Technology transfer would typically occur later in the technology development cycle when the implementation of the technology development has been demonstrated.

This process would repeat for the set of technology developments that are of potential interest, accumulating a store of information about technology developments that through analysis might lead to the identification of previously undetected technology developments of interest. This scenario to illustrate the technology response cycle for digital preservation served as the impetus for the construction of the technology response model for digital preservation.[5]

4.3 Characterising Technology Responsiveness

The term *responsiveness* suggests that the response will be timely, appropriate, and effective.[6] Technology responsiveness enables a community to develop timely and appropriate responses to emerging technologies through continual monitoring, systematic assessment, and appropriate response. An

[4] This list of indicators builds on the results of the evaluation of information sources for technology developments discussed in Section 2.8.
[5] The development of the technology response model is discussed in Section 4.4 through Section 4.12 with the complete diagram in Figure 4-10.
[6] Responsive is defined as “quick to respond or react appropriately or sympathetically”. ‘responsive’, *Merriam-Webster Online*, http://www.merriam-webster.com/dictionary/responsive (accessed May 5, 2008).

implementation of the technology response model should address all three components of responsiveness –monitoring, assessment, and response.

Visualising a common response to a fire alarm provides a familiar context for delineating the generic characteristics of a response. A fire alarm goes off in a building that contains people, who recognise that the alert may be an emergency. The alarm system responds to the trigger of the alarm and notifies fire emergency staff, who are trained to determine if there is an actual fire based on machine readings or the observation of indicators like smoke and fire. They act accordingly to put out the fire, to protect the endangered, and to track the situation until the emergency is over. These experts continually prepare for variations of emergency scenarios. Some emergency staff develop emergency procedures and others implement them.

In the digital preservation community, digital curators are the emergency staff for digital preservation and technological change is the emergency. Digital curators need to be alerted that a potentially significant information technology development has occurred. Digital curators will need sufficient training and information to develop the requisite skills to assess and respond to technology developments.

Consolidating the results of the technological change and technology response investigations suggests that technology responsiveness for digital preservation will require:

- information and analyses about technology developments to enable the digital preservation community to respond;
- an accumulation of current and historical information about technology developments within the scope of concern for and according to the priorities for the digital preservation community;
- information about standards, legislation, and other organisational developments to provide context and to shape technology assessments;
- tools for capturing, analysing, and synthesising accumulated content; and

- tools and other means for providing access to the content to expand the skills and expertise of the digital preservation community.

The ability to respond to technology developments requires sufficient information and explanation to be able to understand the technology development; criteria and a protocol for evaluating the potential implications of the technology development; and procedures and techniques that enable responders to develop a suitable response to the technology development. These three requirements address capacities and capabilities of a technology response. A fourth requirement is a recognised role that authorises responders to respond, either as individuals, as an organisation, or as a community.[7] The technology response model for digital preservation addresses these requirements.

4.4 Components of the Technology Response Model

The discussion of the technology response model for digital preservation in the rest of this chapter identifies two major components of the model: the functional stages of technology responsiveness, and content captured by and for the technology response model. The functional component consists of six stages. The technology response cycle for digital preservation identified four stages for responding to technology developments*: identify*, *monitor, assess*, and *respond*. The need for two additional stages, *notify* and *select*, was identified. The addition of the *notify* stage stresses the importance of raising awareness about the implications of technological change within the digital preservation community through accessible information about technology developments. The addition of the *select* stage specifies the need to provide a rationale for the explicit commitment of community resources for the study of candidates for technology assessment. This will ensure that resources within the digital preservation community for technology responsiveness are applied to the most significant technology developments.

The discussion of the functional stages addresses the purpose, inputs, steps, and outputs of each stage and identifies capabilities needed to implement the stage with recommendations for tools and techniques to match the needed capabilities.

[7] The roles are delineated in Section 4.4 and otherwise presumed in the discussion of the model. The focus is on what happens and how.

Some of these tools and techniques can be adopted directly and put to use in the technology response model, some would have to be adapted, and some that do not yet exist would have to be defined and developed for use by the digital preservation community.

The other component of the technology response model is content. This component of the model addresses the structuring of information accumulated for technology responsiveness. The content component reflects the inputs and outputs of the model's six functional stages.

The technology response model adapts the approach used in the OAIS Reference Model in defining specialised OAIS functions within functional groups. For comparison purposes, the stages of the technology response model are similar to functional groups in OAIS and the steps of each stage are similar to individual OAIS functions. More generally, this discussion reflects high-level information systems design, i.e., input, process, and output. Information comes into a system, is stored and processed by the system, and comes out of the system when and as requested.

The construction of the technology response model for digital preservation assumed that it would support several roles in the digital preservation community: contributors, content and service managers, assessors, responders, and users of the content and services of the technology response model. A *contributor* is a member of the community who submits recommendations for potential technology assessment candidates, identifies new or previously untapped sources of information about relevant technology developments, and provides reports and other higher level reports and updates based on their areas of expertise and interest. A *content or service manager* would develop, maintain, and make available the accumulated content and the services for enabling technology responsiveness for the digital preservation community through the implementation of the model. An *assessor* is an expert with relevant knowledge and experience to participate in one or more technology assessments. A *responder* is a member of the community (individual or organisational) who acts upon the recommendations from a technology assessment and contributes its results or experiences back to the community. A *user* might be any member of the community, including any of the other roles, who interacts with and utilises the content and services of the technology response model. The discussion of the implementation of the model in Section 6.4 further considers the roles involved in technology responsiveness. The roles might be performed by a human or by a machine. These roles are referred in appropriate places in the diagrams of the stages of the model. An implicit expectation is that if it were implemented by the digital preservation community, the technology response model would rely upon distributed accumulation, manipulation, and use of the content about technology developments. This discussion focuses primarily on the conceptual design of the model to ensure that it is comprehensive and complete.[8]

4.5 Identify Stage

The first stage of the technology response model, ***identify***, addresses the process for including technology developments in the scope of interest for digital preservation. In three steps—*nominate*, *accept*, and *stipulate*—the identify stage determines whether a technology development has relevance for the digital preservation community; if it does, the identify stage determines a priority for monitoring the development and acknowledges the resource commitment for including it in the scope of interest for digital preservation. The interactions of the identify stage are illustrated in Figure 4-2.

The *nominate* step receives recommendations directly from contributors or as the result of analysis by the monitor stage, the second stage of the model, which accumulates information. The nominate step could be an automated or manual process, or both. Automated techniques could search for indicators of new technology developments pertaining to the technology framework and the inventory of technologies for digital preservation in the information accumulated by the monitor stage or in any searchable information source. The nominate step could look for new technology developments using the characteristics of the technologies

[8] Section 6.4 considers implementation issues for the technology response model for digital preservation. The results of applying the technology response model for digital preservation are replicated in the discussion of the technology example.

as search criteria. Indicators might be an increase in citations about a topic, an announcement of a new product, or research reports on aspects of a technology type that address known limitations in implementing or integrating that technology type or specific technology development. Manual nomination could allow contributors to identify topics from outside the implementation of the technology response model that are of potential interest. Automated tools could be used to match the nominated technology development to priorities for digital preservation.

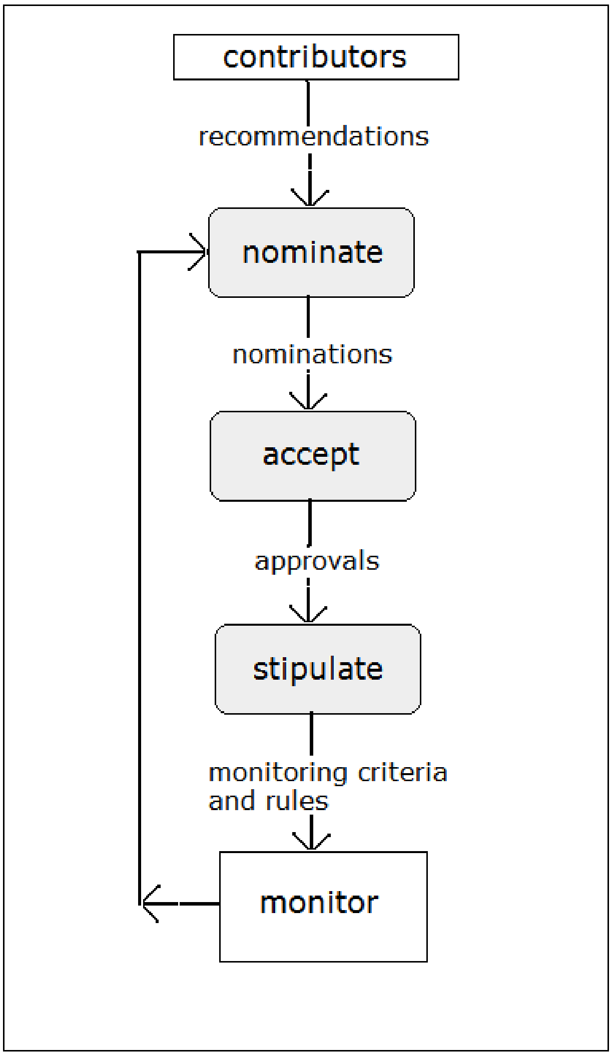

Figure 4-2. The identify stage of the technology response model.[9]

[9] The diagrams in Figures 4-2 through 4-10 depicting the six stages of the technology response model for digital preservation were developed by the author of this thesis to illustrate the steps, inputs, outputs, and interactions of each stage. Consistent conventions have been used in presenting the diagrams of the stages. The steps of the stage illustrated in the diagram appear in boxes with rounded corners and grey backgrounds. Figure 4-2 illustrates the three steps of Identify (nominate, accept, and stipulate). The arrows show the direction of the inputs and outputs. Stages and roles with which the steps interact appear in boxes with square corners. For example, Figure 4-2 shows that Identify interacts with the contributor role and with the monitor stage. These conventions are similar to functional diagrams in the OAIS Reference Model. Both these function diagrams and the OAIS

The *accept* step of the identify stage verifies that the technology development matches the scope of interest and the priority rating. The accept step would require some degree of human review based on established rules and precedents. The purpose of the accept step is to limit technology responsiveness to technology developments that have the greatest potential relevance for digital preservation. The technology framework, the inventory of technologies, and the prioritisation process would be applied by the accept step to define the appropriate scope of interest for digital preservation.[10] The accept step could be supported by tools to classify and accept categories of nominated technology developments. For example, any technology development pertaining to the storage of digital content might be automatically accepted because being aware of these developments is an established digital preservation need. Exploratory technology forecasting techniques could be adapted for reviewing and accepting nominations.

The *stipulate* step establishes rules, search criteria, or projected advancements associated with specific technology developments or technology types to enable and inform monitoring. For example, a search criterion might be provided by the identify stage to the monitor stage to review marketing reports for indicators that a repository software product exceeds 30 percent of the market share, reflecting broad use of the repository software and the potential need for a technology assessment. The stipulate step uses the technology framework and inventory of technologies for digital preservation as a framework and the prioritisation criteria as a guideline to define rules for the monitor stage to use to accumulate relevant information about selected technology developments.

The identify stage represents an important vetting process for technology responsiveness. The inputs to the identify stage of the technology response model are recommendations of technology developments for monitoring. These are

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function diagrams reflect principles of the Unified Modelling Language (UML). For a brief overview of UML see Mandar Chitnis, Pravin Tiwari, and Lakshmi Ananthamurthy, 'UML Overview,' *developer.com*, http://www.developer.com/design/article.php/1553851 (accessed May 10, 2008).

[10] The findings from the investigation of the scope of interest in technology developments for digital preservation discussed in Sections 2.5 and 2.6 suggest that the nominate step will also detect technology developments that fall outside the scope of interest or that may be matched to the scope of interest that another community is monitoring.

received externally from contributors or internally from the monitor function. The nominate step reviews the recommendations and forwards nominations that are successfully vetted to the accept step. Approved nominations are sent to the stipulate step for the definition of criteria and rules. The outputs from the identify stage are recommended technology developments for inclusion in continual monitoring that might later be selected as candidates for technology assessment. The outputs also include criteria and rules that are applied by the monitor stage to refine and focus continual monitoring.

4.6 Monitor Stage

The second stage of the technology response model, ***monitor***, enables continual monitoring of technology developments in the scope of interest. Monitor manages the accumulation of information gathered from external sources and the results from other stages of the technology response model for digital preservation. This stage provides the foundation for all of the stages, each of which iteratively returns to the steps and results of the monitor stage as needed. The monitor stage of the technology response model has four steps: *accumulate*, *aggregate*, *elevate*, and *trigger*. The interactions of the monitor stage are illustrated in Figure 4-3.

The *accumulate* step gathers information iteratively from numerous sources based on rules provided by the stipulate step of the identify stage.[11] Gathering information about numerous technology developments and technology types will require automated tools and extensive storage for the accumulated information. The techniques to accumulate information could include Web harvesting to gather information from Web sites, alerts from technology response implementations in other communities, or text mining, a topic covered in Section 3.5. As previously mentioned, the storage would be distributed across the digital preservation community. The scale of grid technology could be a good match for the accumulate step and for the implementing the services for the technology response model as a

[11] The information gathered would generally be available in digital form, although a piece of information might point to a source, e.g., an abstract for a journal article or for a book that is not accessible in electronic form.

whole.[12] The accumulate step was implicit in the technology watch examples surveyed, none of which transparently offered access to information accumulated in completing technology watch reports.

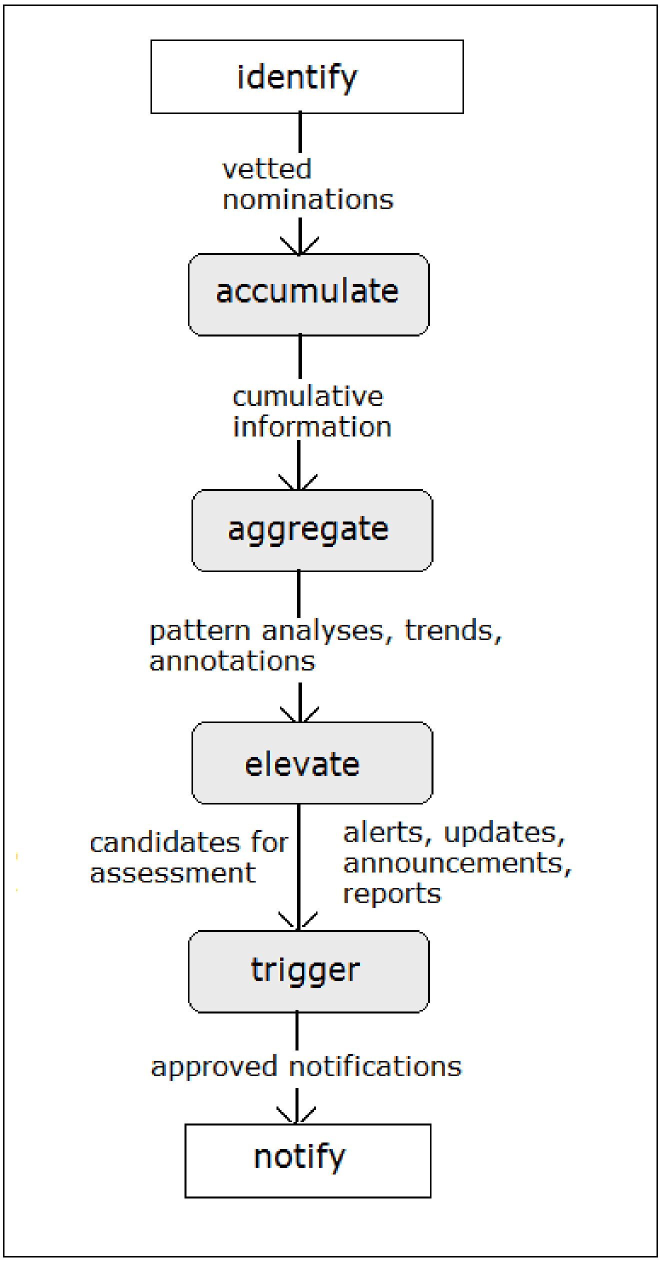

Figure 4-3. The monitor stage of the technology response model.

The *aggregate* step would classify and annotate the accumulated information to make connections between items of information. The process would

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[12] The term grid computing is defined as "a parallel processing architecture in which [computing] resources are shared across a network, and all machines function as one large supercomputer…" 'Grid Computing', *PC Magazine Encyclopedia*, http://www.pcmag.com/encyclopedia_term/0,2542,t=grid+computing&i=43962,00.asp (accessed May 5, 2008).

involve iteratively associating metadata with items of information as the terminology about technology developments evolves and as new technology developments emerge. The techniques for this step would be adapted from data mining, text mining, natural language processing, social networking, and visualisation of information.[13] For example, pattern analysis could look for clusters of information about an existing topic, new topics, an increase in information about a topic, or information about a specific combination of topics. The aggregate step could allow contributors to the implementation of the technology response model to annotate or interact with the accumulated information, but it could also be automated to apply rules for aggregating information and displaying the results. The aggregate step would support automatic notifications for the digital preservation community by searching for specified patterns and events. It would also enable direct interaction with the accumulated content to allow members of the digital preservation community to nominate technology developments for monitoring and assessment, and to be informed about technology developments. Individuals in the digital preservation community should be able to extract or receive information in whatever form is most useful for the implementation of the technology response model to provide the greatest value and impact.

The *elevate* step would apply rules provided by the stipulate step of the identify stage for the aggregate step to highlight milestones, events, or progress pertaining to a technology development of interest. The result of the elevate step would be that a technology development would be identified as ready for a technology assessment. The elevate step might also produce brief alerts or extensive compilations of related items of information about technology developments. Information flagged in the elevate step would be sent to the *trigger* step, which would confirm that the content matches established rules and package the resulting alerts and other outputs to send to the notify stage. These could be simple triggers, e.g., any information about a specific topic, or compound triggers, e.g., a combination of events for related developments. Detection of developments based

[13] See for example: Paul Losiewicz, Douglas W. Oard, Ronald N. Kostoff, 'Textual Data Mining to Support Science and Technology Management', *Journal of Intelligent Information Systems* 15, no. 2 (2000): 99 – 119.

on these rules would both focus the results on technology developments and events of interest, and ensure that the results are comprehensive and current.

The monitor stage is an essential component of technology responsiveness. A technology watch is the most common example of monitoring identified in the investigation of technology responses. The results of the technology watch survey identified several limitations in existing examples, including that a technology watch may not explicitly engage in continual monitoring, typically does not provide access to information accumulated by the technology watch service, does not commit to maintaining the accumulated information after technology watch reports are completed, and does not explicitly include assessment, although some technology watch examples do.

The input to the monitor stage is the cumulative information gathered by applying rules provided by the identify stage.[14] The aggregate and elevate steps of the monitor stage are points in the technology response model where technology forecasting techniques would be applied to analyse information about technology developments. Other inputs to the monitor stage would be annotations by contributors, technology assessments, and other outputs of the technology response model stages. All of these would contribute to the accumulation of information managed by the monitor stage. Processing the store of information to highlight significant developments is the essence of monitoring. The outputs from the monitor stage, as distributed by the notify stage and indirectly by the assess stage and the respond stage, would contribute to the role of technology responsiveness in informing and educating the digital preservation community.

[14] The range of information from technical sources for technology responsiveness was discussed in Section 2.8 on information sources on technology developments and Section 3.5 on text mining. Additional sources for digital preservation technology responsiveness would be reports and results from digital preservation research projects; standards, policies, procedures, and practices developed or adopted by the digital preservation community; examples of organisational policies and practice; digital preservation conference proceedings; professional literature produced by the digital preservation community; and examples of digital preservation curriculum.

4.7 Notify Stage

The third stage of the technology response model, ***notify***, generates alerts using triggers to identify technologies that may be significant for digital preservation, as defined in Section 2.5. The stage consists of two steps: *process* and *send*. The interactions of the notify stage are illustrated in Figure 4-4.

The *process* step accepts alerts from the trigger step of the monitor stage, matches the alerts to the preferences of users, and forwards the processed alerts to the *send* step. Some notifications would initiate the technology assessment process and would be forwarded to the *select* stage. The *send* step simply batches alerts and sends the alerts: an important step for technology responsiveness, but straightforward. A service such as Yahoo news or Google news that allows users to identify topics of interest and set the frequency for receiving updates on them could be adapted for this stage of the model. Both steps should be automated to ensure that notifications are timely and comprehensive. Either the process or send step may require human input for error recovery, testing, verification, and modifications of rules.

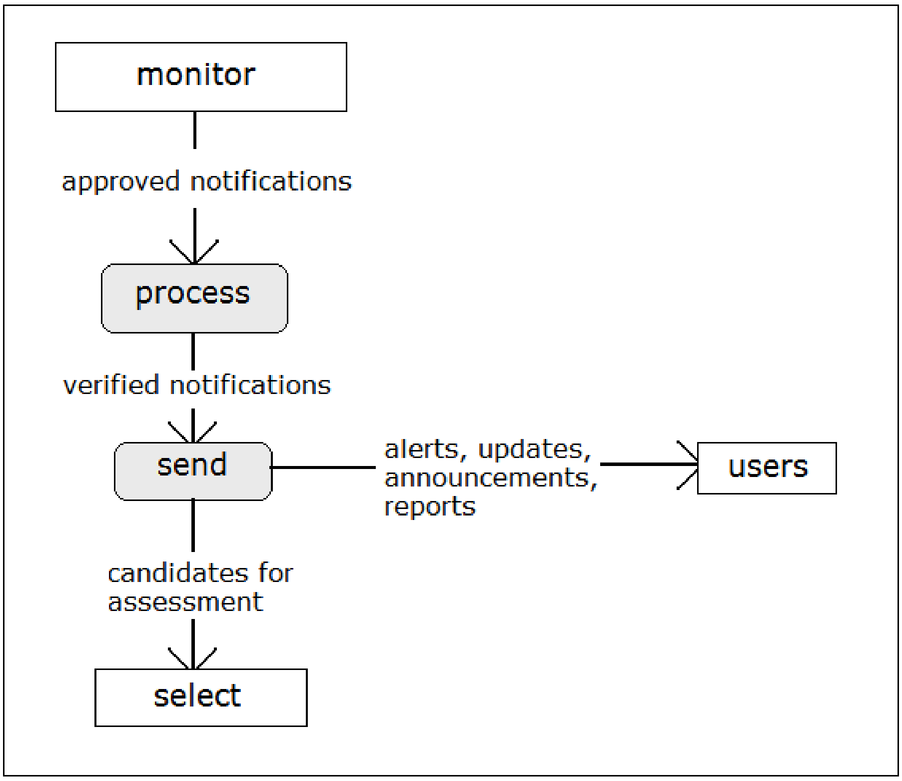

Figure 4-4. The notify stage of the technology response model.

The ability to notify a community is an essential characteristic of responsiveness. The inputs to the notify stage are alerts and other outputs from the trigger step of monitor. The outputs from the notify stage are alerts according to the specifications of contributors and users of the implementation of the technology response model. The notify stage could be viewed as an extension of the monitor stage, but the act of notifying is so important for enabling technology responsiveness that notify is separated out as a distinct stage.

4.8 Select Stage

The fourth stage of the technology response model, ***select***, determines if a technology development identified in the alert sent by the notify stage warrants a technology assessment at the time of the notification or at all. Timing is important for technology assessment because there are too many technology developments to undertake an assessment of every development that might be nominated. Possible recommendations from the select stage could be: continue monitoring the technology development for some period of time or until a specific milestone is marked, broaden or deepen the scan to associate related or specific developments, begin a technology assessment, or recommend immediate action. One objective of monitoring is to identify technology developments for assessment. The select stage serves as the bridge between monitoring and assessment by determining the appropriate timing for a technology assessment based upon available information. The select stage consists of three steps: *recommend*, *decide*, and *assign*. The interactions of the select stage are illustrated in Figure 4-5.

The *recommend* step would receive the notification of a potential technology assessment and recommend an action. The recommend step analyses the notification, gathers additional information from the monitor stage as needed, and generates a report recommending whether a technology assessment should be undertaken. Reviewers of notifications might require supplementary information, consider the results, seek advice and confirmation within the digital preservation community, and/or develop a recommendation. The recommend step is familiar to the digital preservation community because it is similar to the process archivists use to determine if records should be appraised, i.e., evaluated for long-term retention, or to the selection process used by librarians for reviewing possible additions to library holdings. The recommend step could be supported by polling tools depending on the scope of the report and the size of the recommending body. The recommend step may annotate the notification and recommend further monitoring. If the recommendation is to proceed with a technology assessment, that recommendation is sent to the decide step.

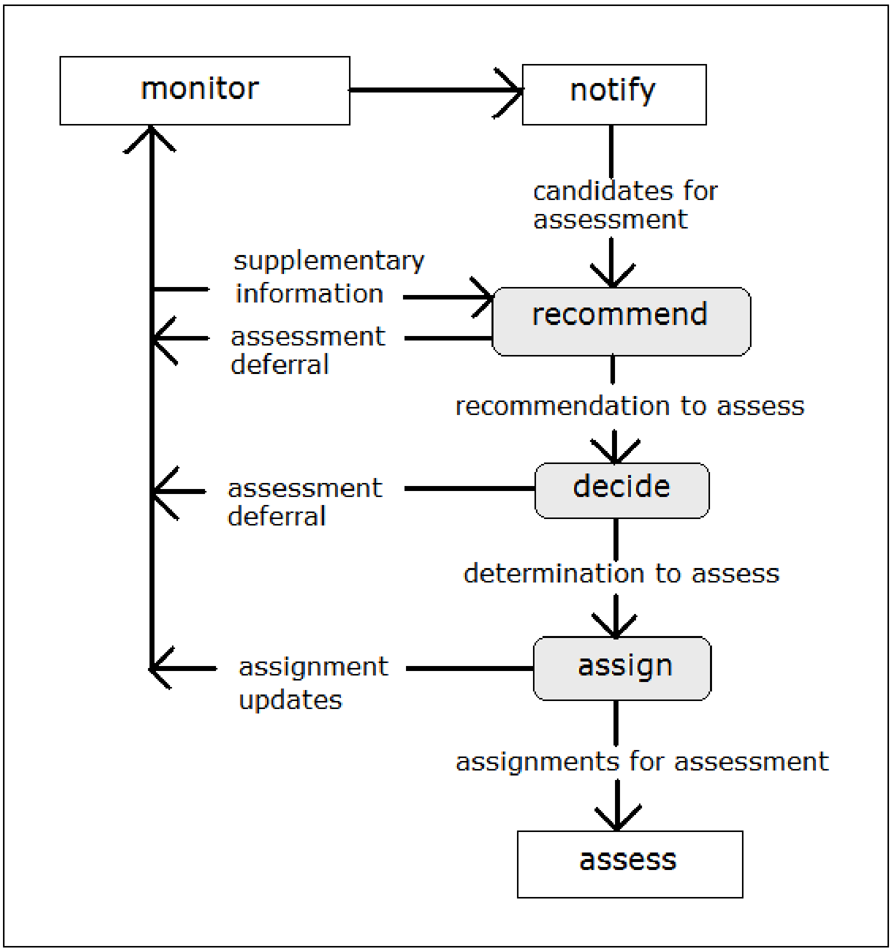

Figure 4-5. The select stage of the technology response model.

The *decide* step may be either an organisational or a community step, depending on the context in which the technology response model is implemented. If the decision is not to proceed with the assessment, the topic may be returned to the monitor stage for monitoring until a specified milestone or other trigger is detected. If the decision is to proceed, the *assign* step matches the assessment with an appropriate technology assessment team. Depending on the scale of assessment, an assessment might be broken into parts and distributed, might be sent to more than one team to get differing results for comparison, or might be undertaken by an individual. Most technology assessments would be complex enough to require the combination of skills provided by a team approach. In practice, the select stage may require time to identify reviewers to make a determination about technology developments proposed for a technology assessment and then to assign the assessment to an appropriate team.

The select stage was added to the technology response model based on the observation that the selection process for technology developments in technology watch reports is typically not transparent and the community that a technology watch serves may not be actively involved in establishing priorities. The inputs to the select stage are notifications from the notify stage that a technology development might warrant a technology assessment. Outputs from the select stage would be technology assessment assignments, recommendations for modifications to monitoring rules based on the review of the notification, and justifications for deferring a technology assessment that would be included in the store of information about technology developments.

4.9 Assess Stage

The fifth stage of the technology response model, ***assess***, initiates and conducts the selected technology assessment.[15] Assessment relies upon continual monitoring and is tested and made meaningful when the recommendations developed by an assessment are acted upon in the form of a response by individuals, an organisation, or the community at large. The intent of the assess stage is to enable the digital preservation community to prepare for the impact of new technologies. The assess stage could be applied to any technologies on the inventory discussed in Section 2.6. The assess stage of the technology response model consists of four steps: *trawl*, *scope*, *analyse*, and *evaluate*. The interactions of the assess stage are illustrated in Figure 4-6.

[15] Section 3.3 discussed technology assessment as one of four technology response types.

The *trawl* step explores the broadest context or landscape of technology developments. The trawl step provides the history, background, key themes, and relevant developments that have or could influence the development of the technology and discusses the environment in which the target technology is developing.[16] The trawl step relies upon a more focused version of the tools for continual monitoring that accumulate data from the broadest possible range of sources and tools that identify significant technological change based upon trends, spikes in activity, and combinations of related developments. This step pulls as much information as possible from the information accumulated by the monitor stage and continues to extract information from and return results to the monitor stage throughout the assessment process. The initial results gleaned from the information accumulated by the monitor stage provide the starting point for the technology assessment. Tools to implement the trawl step should enable the compilation, regeneration, and dissemination of these results.

The *scope* step studies the major category into which the technology development fits. The objective of the scope step is to understand the nature and status of developments related to the category, to describe the context for the category in which the target technology fits, and to provide a basis for comparing the target technology with the dominant technology at the time of the assessment. The scope step defines a review framework and criteria used in the analyse step. Using topics and issues identified by the trawl step, the scope step drills down into those issues, discovers other topics and issues, and develops a broad, descriptive portrait of the technology category that the technology assessment is targeting. This portrait is analysed to identify key developmental factors, issues, characteristics, and priorities that provide the evaluation framework and criteria. The scope step requires a much more focused and formal set of resources than the trawl step. The

[16] In studying technology developments, it can be essential to understand the original purpose of the technology or its development context. If the technology emerged from a particular domain or to meet specific kinds of requirements, being aware of those early influences will be important in understanding the development and evolution of the technology. For example, knowing that geospatial information systems were developed to address requirements specific to cartography and geography is essential to understanding the presence or absence of functionality in geospatial systems as these systems have been expanded and adapted for use by other domains and to understanding the operation of software products that fall into this category of technology developments. The comprehensive historical background of technology developments, including component and upper level technologies, can explain in later stages why particular paths or kinds of development did or did not occur.

full range of sources identified by the trawl step supplements the sources gathered in the scope step. The scope step requires a systematic review and analysis of core literature in relevant domains. Tools to enable the scope step would include the capability to identify additional sources, apply qualitative analysis to the results of the trawl step to identify themes and topics, perform advanced searches, and capture results. The scope step produces a framework and a set of criteria for use in the analyse step.

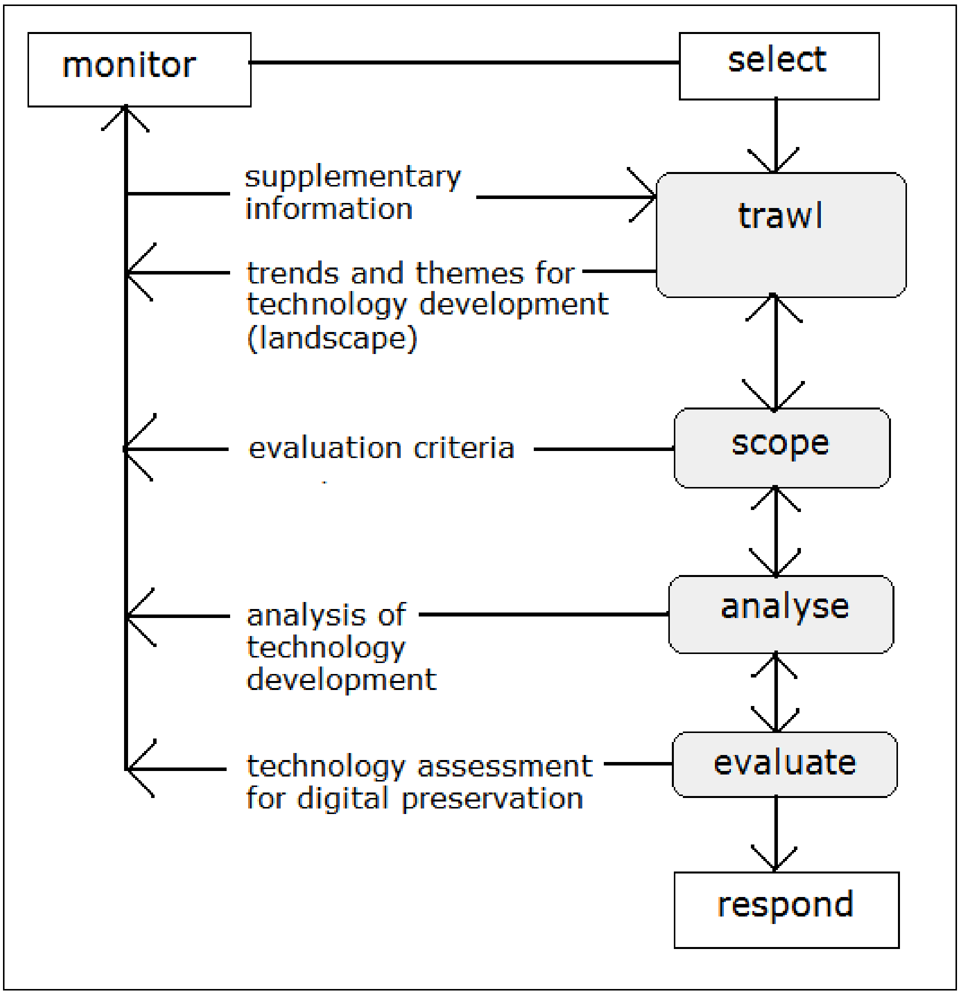

Figure 4-6. The assess stage of the technology response model.

The *analyse* step identifies the key characteristics, concepts, features, limitations, potential, and development trends relevant to the target technology. This step uses the evaluation criteria defined in the scope step to frame the investigation of the technology development. The analyse step focuses on the specific technology that is the subject of the technology assessment, e.g., object-based systems. A comparison of the emerging technology and the dominant technology in that technology category at the time of the technology assessment may be included in the analyse step. The analyse step requires more of a mix of contemporary and historical sources than previous assess steps to be able to understand the factors that influenced the emergence of the technology development, for example. This step involves in-depth analysis to provide a foundation for the evaluate step.

The *evaluate* step produces a full evaluation of the technology development that brings together the results of the first three steps of the assess stage, identifies and discusses the implications of the target technology for enabling or inhibiting the preservation of digital content, and provides recommendations for making the most of the opportunities offered by the technology development or avoiding the potential threats to digital content and management introduced by the technology development. A technology assessment reflects the status of a technology development at a specific point. The results of the evaluate step include the identification of the implications of the technology development for preserving digital content. Conducting a series of technology assessments for each emerging technology in a technology category could provide a time series for digital preservation illustrating the evolution of technology categories and the related evolution of digital preservation strategies. The evaluate step uses all of the findings from the trawl, scope, and analyse steps as the basis for considering the preservation implications of the target technology development. Few new sources of information would be added for this step. The primary outcome of the evaluate step is recommendations for formulating digital preservation strategies that address the implications of the technology development identified by the technology assessment.

The sequence of steps for a technology evaluation identified the layers of context needed for identifying and understanding the implications of a technology development for digital preservation. The diagram in Figure 4-6 maps the steps of the assess stage onto the contextual layers diagram for a technology assessment that was introduced in Section 1.7 in Figure 1-1. The trawl, scope, and analyse steps each iteratively return to the monitor stage for additional information as needed. A primary purpose of the monitor stage is to enable technology assessment; the other benefits of the monitor stage are secondary because assessment enables response and that is the desired outcome of the model. The assess steps are sequential, iterative, and interdependent. The results of each step may have independent value. Depending on the results of the first stages of the technology assessment, all four steps might not be completed. The results of each completed step would be fed back into the monitor stage, and the technology assessment might be resumed later when essential component developments or other factors combine to reinitiate the technology assessment process. The fundamental components of the technology assessment method are the same regardless of the technology development evaluated.

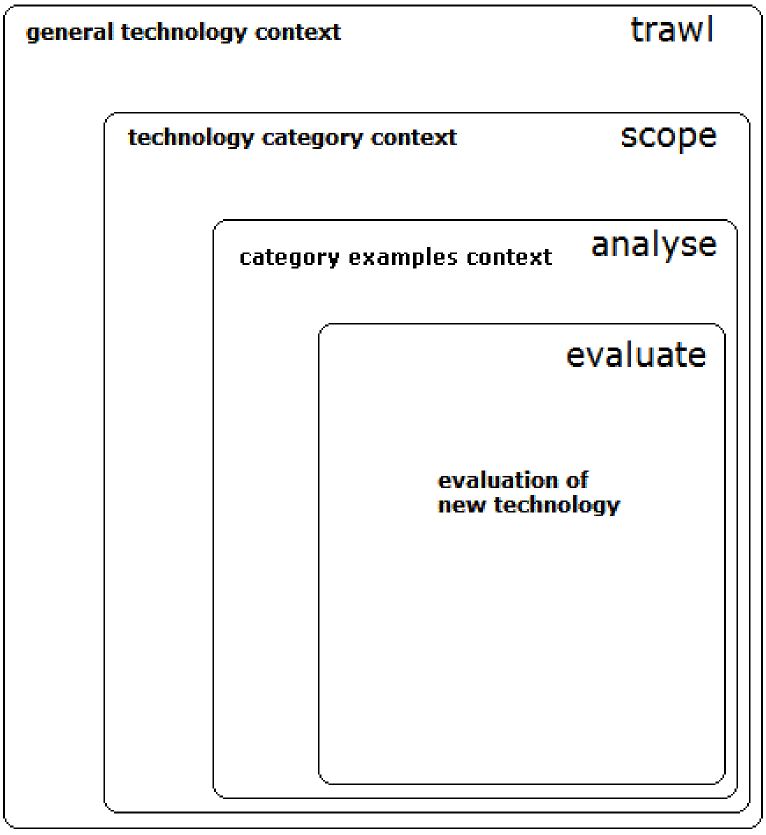

Figure 4-7. The assess steps mapped to technology assessment layers.

Technology assessment is expensive because the process requires time, expertise, equipment, and other resources. The select stage is important for establishing and justifying the need for individual technology assessments. The timing of a technology assessment is crucial: assessment too early in the development of a technology might waste time and money; assessment too late may leave the digital preservation community unprepared. The assess stage might result in a decision during the completion of the technology assessment to defer the completion of the assessment until a specific event occurs or to reconsider the technology development after a specified time. This type of recommendation from the assess stage would be returned to the monitor stage to include in the proscribed monitoring scope and resubmitted to the select stage for consideration when the recommendations for reassessment are met. The technology assessment team's recommendation might be accepted or the technology assessment might be reassigned. The assignment aspect of the select stage is important because it recognises the need to apply a combination of skills and perspectives to a technology assessment to produce a balanced result and the most effective recommendations.

The inputs to the assess stage are iterative batches of information to populate the contextual layers around a technology development that enable an assessment. The outputs of the assess stage are the results of each step, which may have standalone value and would be added to the store of information maintained by the monitor stage, and the recommendations developed by the technology assessment.

4.10 Respond Stage

The sixth stage of the technology response model, *respond*, formulates and carries out responses to technology developments as formulated by the recommendations of technology assessments. The respond stage has three steps: *formulate, measure,* and *adjust*. The interactions of the respond stage of the technology response model for digital preservation are illustrated in Figure 4-8.

Based on the results of the assess stage, the *formulate* step produces recommendations that could call for community action, encourage preservation strategies for organisations, initiate beta testing of preservation strategies by several organisations, recommend candidates for technology transfer, or organise research projects by individuals or groups.

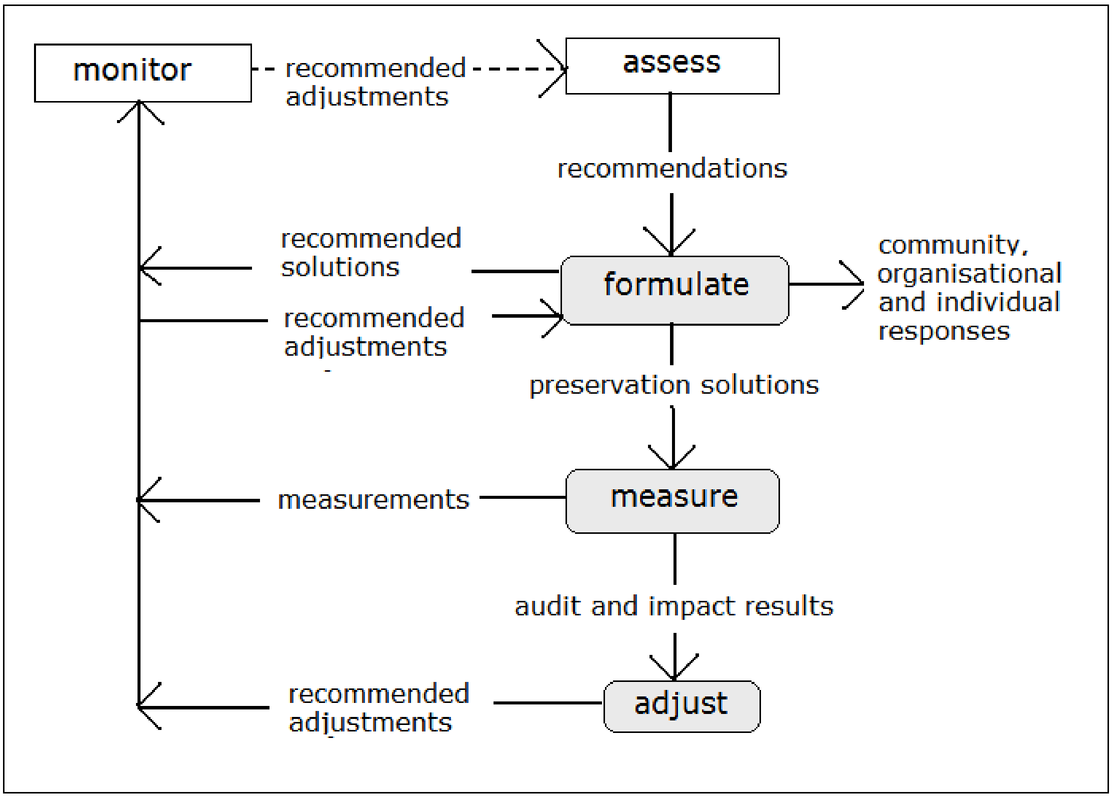

Figure 4-8. The respond stage of the technology response model.

There has been little discussion in the digital preservation literature of the characteristics of a digital preservation response to technology.[17] There is a corresponding lack of standards for the development and implementation of digital preservation strategies. The diagram in Figure 4-9 addresses this absence by identifying three components for formulating a response to technology developments for digital preservation: a preservation profile, a preservation scenario, and a preservation solution. A preservation profile reflects the organisational context in which preservation strategies and actions would be implemented. A preservation scenario addresses the specific technology developments to which the technology assessment applies. A preservation solution becomes appropriate when it effectively combines the organisational context and the optimal means for preservation. Information about each of the response components would be fed back into the accumulate step of the monitor stage.

[17] The PLANETS project is focusing on the automatic generation of preservation plans based on the type of digital content as determined by file type and other content characteristics. The results of this project may ultimately lead to standards for this aspect of a digital preservation response, but more comprehensive standards are needed. Stephan Strodl, Christoph Becker, Robert Neumayer, and Andreas Rauber How to Choose a Digital Preservation Strategy: Evaluating a Preservation Planning Procedure. Proceedings of the International ACM/IEEE Joint Conference on Digital Libraries (JCDL) (Vancouver, Canada: JCDL, 2007).

The *measure* step proves the effectiveness of a response by measuring the impact and outcomes of a response. The need for this step became apparent in evaluating the prevention technology response examples (technology assessment) in Section 3.3.[18] Techniques from technology forecasting could be adapted for measuring the effectiveness of a response to technology developments for digital preservation. Measurements of the impact of responses would be accumulated by the monitor stage as additional information to inform the digital preservation community about technology developments.

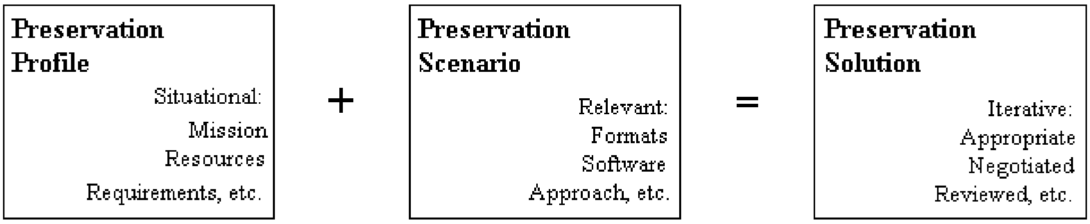

Figure 4-9. Components of a digital preservation technology response.[19]

Measuring the impact of a response to a technology development may suggest action at the *adjust* step. Major adjustments may lead to a recommendation to repeat the assess stage and redo the technology assessment; minor adjustments may suggest repeating the formulate step. Adjusted responses would also be accumulated by the monitor stage to inform the development of future responses and to inform the digital preservation community about the current status of technology developments and existing responses.

Responses may be implemented at the community, domain, and institutional levels. The respond stage represents the best justification for the technology response model. It is the essence of being responsive to technology developments, but it can only be effective if the other stages function properly. The respond stage is the reason for the technology response model to exist. There are many benefits of the other stages of the model, e.g., awareness raising, information sharing,

[18] The recommendation from Guba and Lincoln to include audit in evaluation highlighted the importance of this stage of the technology response model for digital preservation. Guba and Lincoln, *Fourth Generation Evaluation*, 248.

[19] The author of this thesis developed the diagram in Figure 4-9 to illustrate the component parts needed to formulate a digital preservation response to technology.

education, policy and procedural development, but responsiveness implicitly requires a response.

The inputs to the respond stage are technology assessments with recommendations for appropriate responses. The outputs from the respond stage include responses in the form of new and enhanced tools, workflows, and strategies for digital preservation; innovations developed through technology transfer; measurements of the impacts of responses; and adjusted responses.

4.11 Combining the Stages

In practice, the stages of the technology response model as applied to individual technology developments would vary in duration and some stages might never occur, depending on the development cycle of technology developments. For example, a technology development might be monitored over many years, but never achieve a milestone that flags the technology development as a candidate for technology assessment for digital preservation. Technology responsiveness would support the requirements for each of the stages and capture the inputs and outputs generated at each stage. The six stages of the model together would enable technology responsiveness for digital preservation.

The illustration of the technology response model for digital preservation in Figure 4-10 highlights the dominant roles in technology responsiveness of the monitor, assess, and respond stages and the important but more minor roles of the identify, select and notify stages. The monitor stage is represented by a store of accumulated information within the larger grey box to suggest the steps of the monitor stage: accumulate, aggregate, elevate, and trigger, and the associated services that would enable the monitor stage. The monitor stage is the information engine and driver for technology responsiveness. The identify stage appears half in and half out of the monitor stage because identification can occur by analysing the internal content of the monitoring store or through an external recommendation or detection. The assess stages show iterations for a technology development because the result of an assessment might be that more monitoring is needed for a future technology assessment or the technology development might evolve and require an additional technology assessment, for example. Accordingly, the respond stage is iterative because each iteration of a technology assessment would result in response variations at the community, organisation, and individual levels that reflect the requirements of each context. The outputs through the notify, assess, and respond stages reflect examples of the content model, as discussed in the next section. Specifying the outputs in this way recognises that each of the major stages – monitor, assess, and respond – contributes to technology responsiveness for digital preservation.

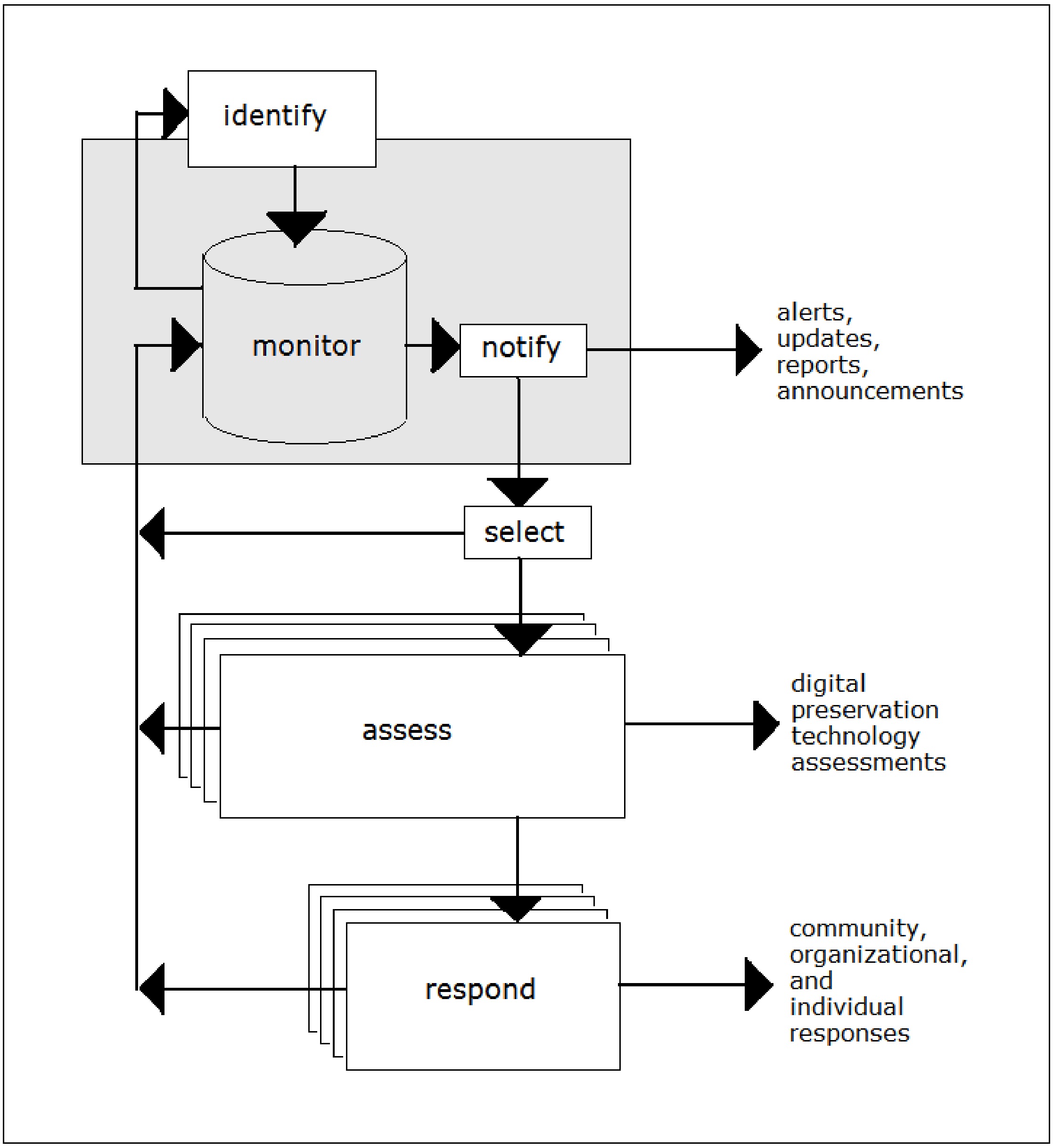

Figure 4-10. The technology response model for digital preservation.

4.12 Content of the Technology Response Model

This section reflects the analysis of the types, value, and purpose of information sources about technology developments for technology responsiveness. The content captured for and contributed to the implementation of the technology response model would be accumulated in the monitor stage with the aid of automated means provided by techniques for harvesting and specialised tools. Comprehensive content that includes both contemporary and historical information is essential to technology responsiveness. The functionality of the technology response model discussed in the previous sections of this chapter is applied to the content.

The analysis of information sources about technology developments identified a range of information sources and the value and use of types of information sources for technology responsiveness.[20] A technology response model implementation should gather information about technology developments across any domain that produces relevant information. Content accumulated through continual monitoring will include information of all kinds, e.g., citations for online and hard copy resources in any domain; research observations and results; formal and informal information from Web sites and other Internet sources; examples of relevant policies, procedures and practice; annotations, updates, and user comments; and information in any form, e.g., text, audio, image, video. The content of an implementation of the technology response model will include raw data and information collected from any available source that describes, discusses, announces, or in any way pertains to technology developments with potential relevance for digital preservation. It will also include processed information produced by the implementation of the technology response model from the accumulated information in the form of updates, alerts, reports, technology assessments, and technology response examples. All the stages of the technology response model generate the information accumulated in the model.

[20] The evaluation of information sources on technology developments is discussed in Section 2.8.

In thinking about managing the accumulation of content for technology responsiveness, a reference point is the classic information hierarchy. This hierarchy is often referred to in the information science and knowledge management domains as DIKW or Data, Information, Knowledge, and Wisdom. [21] The hierarchy is typically depicted as a pyramid with data at the base of the pyramid and wisdom at the pinnacle. The use of a pyramid focuses on the path to wisdom by building on data, information, and knowledge, and illustrates the decrease in volume through distillation from data to wisdom.

The content model for the technology response model, depicted in Figure 4-11, stresses the equal importance of data, information, and knowledge. This balance in the content model addresses the lack of transparency and lack of access to information noted in the survey of technology watch examples. The content model also illustrates the importance of accumulating data to inform contemporary and future technology assessments. In the proposed content model for the technology response model, the pyramid is flattened into this iterative information cycle to demonstrate the key principle that raw information (data) is as valuable to processed information and acquired knowledge, may be used repeatedly in alerts and assessments for many different kinds of technology developments and should be as or more accessible than the more processed outputs to encourage the digital preservation community to explore and investigate new technologies.

The data box on the left-side of Figure 4-11 represents inputs into the implementation of the technology response model as the information accumulated by monitoring and the results generated by other stages of the technology response model. The information box represents the aggregate, elevate, and notify steps of the monitor stage of the technology response model. Data are transformed into information through the iterative loops of the aggregate and elevate steps, during

[21] The original hierarchy was developed and introduced in article by Harlan Cleveland in 1982. This is the citation for the information hierarchy: Cleveland was referencing a play on which T.S. Eliot collaborated, *The Rock*. The lines from the play are: “Where is the wisdom we have lost in knowledge? / Where is the knowledge we have lost in information?” The model Cleveland originated was later expanded by Zeleny and Ackoff. Harland Cleveland, ‘Information as Resource’, *The Futurist* (December 1982): 34-39. T.S. Eliot, *The Rock* (London: Faber & Faber, 1934). Milan Zeleny, ‘Management Support Systems: Towards Integrated Knowledge Management’, *Human Systems Management* 7, no. 1 (1987): 59-70. Russell L. Ackoff, ‘From Data to Wisdom’, *Journal of Applied Systems Analysis* 16 (1989): 3-9.

which analytical tools are used to identify patterns, trends, and significant occurrences in the data and during which analysis by tools and humans generate alerts and trend analyses, for example. Analysis of content is an ongoing process in an implementation of the technology response model. Any of the roles associated with the model (contributors, content and service managers, assessors, responders, and users, as identified in Section 4.4) should be able to run analyses, request analyses, or receive routine and ad hoc analyses as part of the services provided by the implementation of the technology response model. The iterative communication phase of technology responsiveness disseminates white papers, assessments, and other outputs to the digital preservation community that equate to the common products offered by many of the technology watch examples surveyed. The intended outcome is that the community becomes more aware of and knowledgeable about technology developments. The iterative gathering, analysis, and dissemination phases over time lead to acquired understanding and wisdom about technology developments for the digital preservation community.

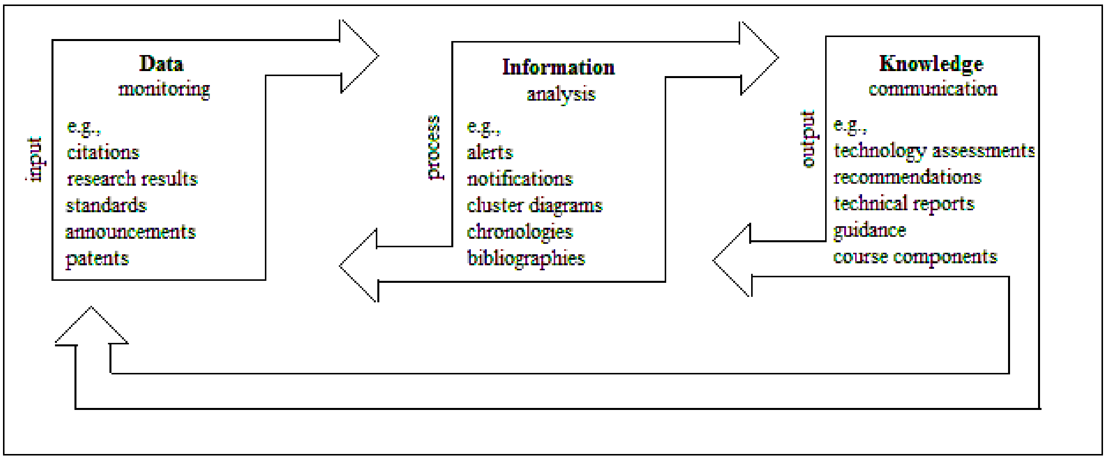

Figure 4-11. Content component of the technology response model.[22]

4.13 Conclusion

The need for the digital preservation community to be responsive to technology is an acknowledged challenge for the digital preservation community.[23]

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[22] The author of this thesis developed the content model in Figure 4-11 to illustrate the types, interactions between, and roles of the content that are accumulated and managed by the technology response model for digital preservation.

[23] Section 1.5 traced the emergence and acceptance of this need.

The proposed technology response model addresses this requirement for the digital preservation community by identifying the functions, roles, and content of a technology response model for digital preservation. This investigation concluded that technology responsiveness requires both continual monitoring and comprehensive assessment of significant technology developments. Continual monitoring informs a community about relevant technology developments and identifies potential candidates for technology assessment. Comprehensive technology assessments provide a deeper understanding of significant technology developments and produce recommendations to devise and implement appropriate responses.

The implementation of the technology response model by the digital preservation community would provide flexible and evolving levels of access to accumulated current and historical information about technology developments in the form of alerts, reports, technology assessments, tools, and procedures to be able to make well-informed decisions and to formulate effective strategies for preserving digital content. The potential outcomes of implementing the technology response model for the digital preservation community to respond to ongoing technological change would include innovations or improvements in digital preservation capabilities through development or adaptation, digital preservation strategies that address the characteristics of new or changed technologies, and a more comprehensive awareness and deeper understanding of relevant technology developments within the digital preservation community, as well as recommendations for avoiding potential threats to existing digital content.

Chapter 5. Demonstrating the Technology Response Model

5.1 Introduction

Using object-based systems as an example, the purpose of this chapter is to demonstrate the model by applying it to a complex technology development that is of potential interest for digital preservation. The objectives of the demonstration were five-fold: to verify the completeness and utility of the model by applying it to a plausible example, consider the logic and validity of the sequence of stages and steps, exemplify the types of inputs and outputs anticipated for each stage, complete the fifth step of constructive research methodology by demonstrating the solution appropriately addresses the problem, and contribute to the development of the list of implementation considerations that are discussed in Section 6.4. The example illustrates how implementing the model will enable the digital preservation community to detect, monitor, assess, and respond to potentially significant technology developments, such as object-based systems.

In practice, the implementation of the model would be sustained over a period of time by many contributors and users within the community and would reflect the accumulation of intersecting results generated by applying the stages to numerous technology developments concurrently. As discussed in Section 2.3, the duration of the innovation stages (invention, innovation, and diffusion) of an individual technology development – and so, the duration of the stages of the model – would be measured in weeks, months, and very often years. The potential duration of the stages and extent of results that would be accumulated posed a challenge for depicting the example. In addition, the intent of this example is to validate and typify the components of the model, rather than to produce a full complement of specific results for object-based systems. Although the example cannot and is not intended to replicate the content and outcomes that a community-wide implementation of the model would produce, it suggests the intended results. The aim was to provide sufficient information, explanation, and illustration to meet the previously stated objectives.

In this chapter, information about the example, object-based systems, emerges in the sequence and at the level of granularity it would in an implementation of the model. As in an actual implementation, when a technology development is detected and continual monitoring begins, there would typically be little widely available information and only limited awareness about the technology development within the community. Familiarity with and understanding of the technology development would increase as monitoring continues, providing a base of information for the assessment and response.

This example, object-based systems, was introduced in Section 1.7. Object-based refers to the manner the system uses for storing digital content. Object-based systems utilise object-oriented programming principles to model and store digital content as modular digital objects.[1] Object-oriented programming principles are defined in Section 5.6 in the discussion of the assess stage, the point at which advanced concepts about the technology development would be examined in preparation for the development of a response. The emergence of any information system that might serve as a repository for digital content would be of immediate interest to the digital preservation community. The discussion of the example considers the implications of object-based systems as a specific type of repository and illustrates how the model would facilitate the development of an appropriate community response to this type of technology development.

The following sections discuss each of the six stages of the technology response model for digital preservation as applied to the example. For convenience, the purpose of and the steps within each stage are restated from Chapter 4. The remainder of the sections discusses the timing and other characteristics of the outcomes of the stage for the community through samples and instances. For ease of reading, the process of the model is primarily discussed in the text and the examples of information and other outputs that would be available at each stage are often captured in the footnotes.

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[1] Reflects the Oxford English Dictionary definition: 'object-oriented', *OED Online* (Oxford University Press, December 2007) http://dictionary.oed.com/cgi/entry/00329075se24 (accessed 5 Jan. 2008).

5.2 Identify Stage

The *identify* stage of the technology response model nominates technology developments that should be included in the scope of interest for continual monitoring or might be considered for a technology assessment. The identify stage includes three steps: nominate, accept, and stipulate. At this stage of the model, little or no information relevant to the technology development , although incidental information might have been accumulated in relation to other technology developments that might lead to the detection of a new technology development to monitor. A technology development might be detected at any point from its invention stage forward. If the model had been in place and implemented, object-based systems might have been detected in the late 1960s when object-oriented programming principles were introduced, but most authors agree that the technologies needed for object-based systems to flourish in the mainstream have only been emerging since the early 1990s[2]. Once detected, monitoring would continue until the technology development had matured to the point of warranting an assessment.

The *nominate* step receives recommendations of technology developments for consideration from contributors (humans) or from continual monitoring underway in the monitor stage (see Section 5.3). This example illustrates the nominate step being initiated by a human contributor to make the sequence of the stages easier to illustrate. Triggers that might have been identified by a contributor to nominate object-based systems for inclusion in continual monitoring include an announcement identifying new object-based software products, a marketing report showing an increase in the market share for object-based software products, a technical report or white paper discussing features of object-based software, and

[2] See, for example, Mesnier, et al, identified Swallow (developed in 1980) as an early distributed object store, but distributed object stores really became viable in the early 2000s; Blackford noted that Gemstone (distributed in 1987) was the earliest viable object-based database software, but only later developments allowed for broader use; and Manola noted that SIMULA (an object-based programming language developed in the 1960s) was an early example, but Smalltalk (in use by 1983) was the first viable object-based language. Mike Mesnier, Gregory R. Granger, and Erik Riedel, 'Object-Based Storage', *IEEE Communications* (August 2003): 89; John Blackford, 'The Story of "O"', Personal Computing (29 June 1990): 85; and Frank Manola, 'Object-oriented Knowledge Bases, Part 1', *AI Expert* (March 1990): 29.

references to object-based systems and digital objects in monitored sources.[3] The nominate step then forwards nominations to the accept step.

When a technology development is first detected and nominated for inclusion in continual monitoring, little may be known about it, although references pertaining to the technology development may already have been accumulated by monitoring without the technology development having been identified as relevant. For example, content might have already accumulated about digital objects or persistent storage that would be pertinent to object-based systems and could contribute to a decision to accept a technology development into a continual monitoring program, although additional information would be required for that decision. The *accept* step would confirm that the nominated technology development matches a category in the technology framework or matches a technology on the technology inventory. Some technologies might have features or characteristics that map it to one or more technologies on the inventory. Prior to the technology assessment it would be clear that object-based systems map to the repository category of the technology framework for digital preservation, and digital objects stored by object-based systems map to the object category of the framework.[4]

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[3] See, for example, an announcement identifying a new object-based software products example that would be detected by continual monitoring: db4Objects, 'db4o Version 6 Debuts to Dedicated Community of 15,000 Developers and Growing', press release (2006), http://www.db4o.com/about/news/release/2006_11_14.aspx?AspxAutoDetectCookieSupport=1 (accessed 25 May 2008); an example of a market report for object-based software products: Rick Whiting, 'Channel Partners Question SAP 's Business Objects Deal', *ChannelWeb* (October 2007), http://www.crn.com/article/printableArticle.jhtml;jsessionid=2GWVGE4VAINJ4QSNDLOSKH0CJUNN2JVN?articleId=202400101 (accessed 25 May 2008); an example of a technical report or white paper discussing features of object-based software: Charles Duncan, 'Digital Object Repositories Explained', An Intrallect White Paper (October 2006), http://www.intrallect.com/index.php/intrallect/knowledge_base/white_papers/digital_object_repositories_explained (accessed 25 May 2008); and examples of references to object-based systems and digital objects in monitored sources: Thornton Staples, Ross Wayland, and Sandra Payette, 'The Fedora Project: An Open-source Digital Object Repository Management System', *D-Lib Magazine* 9, no. 4 (2003); J. Bekaert, P. Hochstenbach, and H. Van de Sompel (2003, November), 'Using MPEG-21 DIDL to Represent Complex Digital Objects in the Los Alamos National Laboratory Digital Library', *D-Lib Magazine* 9, no. 11(2003); Robert E. Kahn, and Patrice A. Lyons, 'Representing Value as Digital Objects: A Discussion of Transferability and Anonymity', *D-Lib Magazine* 7, no. 5 (2001); and Alapan Arnab, and Andrew Hutchison Verifiable digital object identity system Proceedings of the ACM Workshop on Digital Rights Management (2006): 19-26. Section 2.8 discussed the potential information sources about technology developments and Section 4.12 discussed the content component of the technology response model.

[4] Section 2.5 discussed the technology framework and Section 2.6 discussed the technology inventory.

If the technology development is matched to the technology framework or inventory, the indicators identified in the *nominate* step would be reviewed in the accept step. Several factors would support the approval of object-based systems for continual monitoring. Announcements of software products suggest that a technology is at least at the innovation stage of the innovation cycle. References to object-based systems in a range of literature suggest growing interest in object-based systems and, therefore, growing potential impact.[5]

Once the technology development is accepted, the *stipulate* step defines rules for the monitor stage to use in accumulating information about the technology development. Initially, the rules associated with a technology development might be very simple. Rules might then be iteratively refined once the technology development is included in continual monitoring and more becomes known about the technology development. Refining the rules might focus the accumulation of information on particularly important characteristics or on advancements that must occur for the technology development to move into the innovation or diffusion stage, for example. The monitoring rules initially associated with object-based systems might be as simple as: search for the terms *object-based systems* and *digital objects*. The features identified in the software announcements or technical reports about object-based systems might be added to extend and focus the search, e.g., object storage, object persistence, and asset management.

5.3 Monitor Stage

The *monitor* stage of the technology response model coordinates continual monitoring of relevant technology developments and organises the accumulation and dissemination of information gathered from external sources and the results from other stages. The duration of the monitoring stage may vary significantly, depending on the rate of the emergence of the technology development. A technology development that is detected early in its development or that is

[5] The majority of object-based systems discussions occur in technology-related literature, but in many areas including artificial intelligence (e.g., Manola), storage systems (e.g., Mesnier, et al), Information Systems (e.g., Eden), and more popular business applications literature (e.g., Blackford). Manola, 'Object-oriented Knowledge Bases', 26-36; Mesnier, et al, 'Object-Based Storage', 84-90; Annon H.Eden, 'A Theory of Objected-Oriented Design', Information Systems Frontiers 4, no. 4 (2002): 379-91; and Blackford, 'The Story of "O"', 83-86.

emerging slowly might be monitored for a long period of time before an assessment is initiated. A technology development that is detected at a later stage of development, is emerging quickly, or receives a strong recommendation from the identify stage as being of particular potential relevance for digital preservation might be highlighted almost immediately as a candidate for technology assessment. In the latter case, monitoring would accumulate and provide information for the technology assessment. The monitor stage includes four steps: accumulate, aggregate, elevate, and trigger. When a technology development is first included in continual monitoring, little or no information would have been accumulated about it. The purpose of monitoring is the development of understanding through awareness. Through iterative accumulation and aggregation, the community would become increasingly familiar with a technology development, in preparation for a possible technology assessment.

The *accumulate* step harvests information continuously from as many sources as possible using the rules provided by the stipulate step of the identify stage. The results of the accumulate step are intended to be as comprehensive as possible.[6] This accumulated content would be made available to users through alerts (see the notify stage in Section 5.4) or through discovery tools and services provided to users for more direct access. Technology responsiveness for digital preservation is enabled by making the results of the accumulate step comprehensive and accessible. In addition to the examples identified in Section 5.2, information accumulated about object-based systems during continual monitoring might include: patents pertaining to technology developments for object-based systems, technical journal articles, news about vendors and software pertaining to object-based systems, and announcements regarding the release and enhancement of tools and software to design and implement object-based systems. Accumulation would be accomplished using techniques to discover and analyse pertinent information for inclusion based on relevance, e.g., text mining, as discussed in Section 3.5. The

[6] The content component for the technology response model discussed in Section 4.12 identified citations, research results, standards, announcements, and patents as examples of data that would be accumulated by monitoring. This information would be associated with keywords and other annotations by automated tools and by human contributors, a process that would enable the aggregate step.

results of the accumulate step refine the rules provided by the identify stage (see the stipulate step in Sections 4.5 and 5.2).

The *aggregate* step identifies, highlights, and documents the connections and dependencies between technology developments. The identification of these patterns would be added to the accumulated content and shared with users. For example, discussions of object-based systems often include references to XML, packaging, and persistent objects.[7] These patterns and relationships might be detected through automated tools or highlighted by contributors who would have access to tools for the annotation of accumulated information.[8]

The *elevate* step processes and annotates the aggregated results to highlight events or characteristics that might warrant an alert or suggest a technology development is becoming ready for an assessment. As continual monitoring detects potential candidates for technology assessment, alerts would increase in number and substance. A candidate for technology assessment might be identified by a combination of increasing references in technology-related literature, detectable references in digital preservation literature, increases in the use of software related to the technology as reflected in marketing or other reports, and identifiable attempts to demonstrate the viability of the technology development.[9] These indicators suggest the growing possibility that the technology development will affect digital content that is created, managed, manipulated, or disseminated by the technology. Applying the rules established in the stipulate step, the elevate step could identify specified milestones or events that were stipulated to prompt a technology assessment. If, for example, a rule states that an indicator of increased use of object-based repositories should prompt a consideration of object-based systems for a technology assessment, the results of a census of institutional

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[7] See for example: Eric Pardede, J. Wenny Rahayu, and David Taniar, 'On Using Collection for Aggregation and Association Relationships in XML Object-relational Storage, *Proceedings of the 2004 ACM symposium on Applied computing* (2004): 703 – 710.

[8] See for example: Maristella Agosti and Nicola Ferro, 'A Formal Model of Annotations of Digital Content', *ACM Transactions on Information Systems (TOIS)* 26, no. 1 (2007).

[9] As early as the 1990s, some authors were encouraging the adoption of the object-based design process for use in developing any kind of system, even before there was broad support or capability for widely implementing object-based systems. Connolly, Begg, and Strachan, *Database Systems*, 783.

repositories documenting planned use of the Fedora repository, an object-based repository package, might trigger a review.[10]

Results from the elevate step in the form of alerts to be sent to users and proposed candidates for assessment are passed to the *trigger* step. Alerts are checked against existing rules to ensure that the alerts and associated compilations of information to be sent out were correctly identified as relevant. All of the accumulated and aggregated content about candidates for technology assessment is brought together in preparation for consideration of the candidate technology and for possible technology assessments.

5.4 Notify Stage

The *notify* stage disseminates alerts about technology developments to the digital preservation community and forwards candidates for technology assessments to the select stage. The notify stage includes two steps: process and send. These two steps would benefit from developments pertaining to messaging mechanisms and reporting on the technology inventory, for example (see Section 2.7). The ability for the digital preservation community to received systematic and continual alerts, updates, and reports may be the most significant contributor to awareness of technology developments within the community.

For alerts, the *process* step receives alerts from the trigger step, matches the alerts to user preferences, and sends correct alerts to the send step. Users might identify broad or specific interests in technology developments. A user might want to receive an alert when references to a particular technology development reach a specified number or ratio of citations, are sustained at a certain level for a specified period of time, include one or more specified topics, are mentioned in a specified manner or type of source, or indicate that a specified milestone has been attained. For example, a user might want to receive an alert about technology developments relating to any type of repository, specifically to object-based systems, or to

[10] Soo Young Rieh, Karen Markey, Beth St. Jean, Elizabeth Yakel. And Jihyun Kim. Census of Institutional Repositories in the U.S.', *D-Lib Magazine* 13, no. 11/12 (2007).

technologies relating to digital objects. Alerts about object-based systems would be disseminated for any of these preferences as a result of continual monitoring.

For technology assessment candidates, the process step would create an index including links to all of the accumulated information relating to the technology development, generate abstracts of the information identified as most relevant to the technology development, and note that updates to the index and abstracts should be generated until the review process by the select stage or the technology assessment itself is completed. The process step might utilise a template or checklist in compiling a technology assessment review package that had been defined for particular types of technology developments. A review package for a technology development in the repository category, such as object-based systems, would be extensive and include references to numerous related or enabling technologies. If a technology development had previously been considered and deferred for technology assessment, the process step might have been given parameters to apply in preparing the review package when the technology development becomes a candidate again. Object-based systems might have been considered and deferred for technology assessment one or more times.[11] In addition to alerts that would be iteratively sent, a review package containing a compilation of information about object-based systems would be forwarded to the send step, reflecting the development and emergence of object-based systems.

The *send* step is simple: it batches and sends the alerts to users and the review packages for the technology assessment candidates to the select stage. Providing alerts to users may be the final step for many technology developments. A technology development might be of interest only in relation to other technologies and may never be identified as a candidate for technology assessment. All relevant technology developments should be included in continual monitoring for technology responsiveness because information about each potentially relevant technology contributes to a greater awareness about and a deeper understanding of technology developments within the digital preservation community. In this example, the review package for object-based systems would be sent to the select

[11] In the 1960s, both object-oriented programming and the relational model were introduced. Since that time, either could have been identified as a technology development that is potentially relevant for digital preservation.

stage. In this example, the compilation of information about object-based systems would demonstrate an increasing actual and potential impact for digital content and, therefore, object-based systems would be processed for technology assessment and the review package forwarded to the Select Stage.

5.5 Select Stage

The *select* stage identifies technology developments that will be recommended for technology assessment. The select stage might result in a decision to implement, defer, or reject a recommendation for a technology assessment. The select stage includes three steps: recommend, decide, and assign. When a technology development reaches the select stage, the digital preservation community would be aware of the technology development, but would not have a deep understanding of it yet or have a common and accepted means for responding to it.

The *recommend* step receives the review package from the notify stage and recommend an action regarding technology assessment. Any technology development that might have an impact on digital content is a potential candidate for a technology assessment for digital preservation. The more likely the impact seems, the stronger the recommendation to initiate a technology assessment should be. A key indicator for a candidate that is a type of repository to recommend a technology assessment would be evidence and examples of the ability to implement the repository type, even in a research context. For object-based systems, there are a number of object-based repository packages now available, e.g., the Fedora repository. The OAIS Reference Model provides a framework of capabilities that a trusted digital repository for digital preservation must be able to address and developers of repository packages are striving to demonstrate conformance with OAIS.[12] As noted in Section 4.8, timing is essential for technology assessment. These activities would recommend object-based systems as a candidate for

[12] A 2006 briefing paper considers OAIS conformance and briefly reviews common repositories, including Fedora, for conformance. Alex Ball, Briefing Paper: the OAIS Reference Model, UKOLN, University of Bath, 2006 http://www.ukoln.ac.uk/projects/grand-challenge/papers/oaisBriefing.pdf (accessed 25 May 2008).

technology assessment with some degree of priority for the apparent immediacy of their potential impact.

Additional indicators would strengthen the recommendation for a technology assessment. Increasing numbers of alerts, for example, demonstrate an increased interest in and potential viability of object-based systems based on detected references both within and beyond the digital preservation community. Reviewers would consider all available information to make a recommendation. Object-based systems would be recommended for a technology assessment when indicators suggest that a growing amount of digital content might be created, stored, or managed by an object-based system. In the example, the potential impact for digital preservation was considered significant enough that object-based systems were recommended for a technology assessment. If the recommendation is not to proceed with a technology assessment, the candidate is returned to the monitor stage with rules for continual monitoring and to guide reconsideration of the candidate for a technology assessment at another time. Until object-based systems warranted a technology assessment, the primary focus of continual monitoring would have been the refinement of rules for accumulation and aggregation to ensure that the breadth and dept of information about object-based systems was captured in preparation for an assessment.

The *decide* step may be completed by the digital preservation community or, more likely, by a group designated by the digital preservation community to reflect its interests and make decisions based on guidelines it defines. If the decision is not to proceed with the assessment, the candidate may be returned to the monitor stage until a specified milestone or other trigger is detected. The decision to proceed with a technology assessment of object-based systems reflects the detected increase in the research and development interest and investment in object-based systems and the increasing capability to create, store, and manage digital content in object-based systems that are feasible for implementation in multiple organisational contexts that are not limited to research prototypes. Once the decision is made to proceed, the *assign* step links the assessment to relevant skills and interests of a combination of assessors.[13] A technology assessment of object-based systems would be assigned one or more assessors.[14] In practice, identifying qualified and available assessors may pose a challenge.

5.6 Assess Stage

The *assess* stage conducts technology assessments that provide the means to devise and implement an appropriate response to the technology development. The assess stage includes four steps: trawl, scope, analyse, and evaluate. It is at the assess stage that the digital preservation community has an opportunity to develop a deeper understanding of a technology development to enable an appropriate response. Individuals within the community may already have an understanding of the technology development and those individuals would be identified as possible assessors. For any assessment, assessors would be sought from domains that have experience with or a demonstrated interest in the technology development to ensure that the recommendations developed by the assessment are comprehensive, accurate, and feasible.

The *trawl* step examines the landscape surrounding the technology development using the review package as a starting point. This step iteratively returns to the monitor stage as new topics are identified and receives updates from the monitor stage. The trawl step for object-based systems provides a broad context layer for the technology assessment and identified three topics that reflect constraints on the evolution of information systems. Storage limitations of the platform of an information system, processing limitations due to size, scale, or complexity, and information exchange limitations are three of the kinds of topics the trawl step would uncover through iterative loops to the monitor stage, applying additional rules from the stipulate step to focus the accumulation of specific results

[13] Section 6.4 includes a further consideration the formulation of technology assessment teams.
[14] The author of this thesis is an example of an assessor who has relevant digital preservation skills, has displayed an interest in object-based systems, and who would bring an organisational perspective to a technology assessment.

for the assess stage.[15] These results would have standalone informational value for technology responsiveness as well as inform the technology assessment.

The *scope* step of the assess stage investigates concepts, components, and key developments in the category of technology for the technology development. In an assessment of object-based systems, the scope step would focus on information systems (or repositories) as the larger category of technology. This process would examine common types of systems to identify essential characteristics and use the results of the examination to create a frame for a technology assessment that could be used for any type of information system. The frame developed for the assessment of the category might be expressed as a set of questions, such as:

- *Do programming languages exist that can be used to implement the information system type?*[16] Programming languages capable of implementing an information system are a virtual prerequisite for an information system because systems cannot be implemented, managed, and used without programming languages.
- *Does a data model exist for the information system type that is ready to be implemented?*[17] The existence of a data model is significant because it suggests a level of maturity that would enable wide implementation of the information system type.
- *Can the information system be implemented on common, contemporary computing platforms?* An information system type that requires a

[15] Platform is one of the categories of the technology framework for digital preservation discussed in Section 2. 5. Until the 1990s, the combination of relatively low density of computer storage and the high cost of storage was a significant factor in the evolution of the platforms upon which information systems are implemented. Grid technology, a term previously introduced and defined in Section 4.6, is one example of a technology development that has removed constraints on storage limitations. Technology-related literature shows that the information exchange capability began with the development of local networks and developed into the Internet, a global information exchange network. *Philosophy and Computing*, 42, 56-61, 76-79.

[16] An information system might be implemented by any programming language that is capable of building the required structure to hold data, of establishing the specified relationships between those structures, and of enforcing stipulated rules for adding, changing, or combining data. See for example: Carlo Ghezzi, and Mehdi Jazayeri, *Programming Language Concepts*, 3rd ed. (Chichester: Wiley, 1998), 9.

[17] A data model defines the organisation and relationships of the information to be managed in a system. The implementation of the system is framed, but prescribed by the data model. See for example: D.E. Avison, and G. Fitzgerald. Information Systems Development: Methodologies, Techniques and Tools (Oxford: Blackwell Scientific, 1988), 55-58.

specialised technology environment or is platform specific will have limited potential impact and perhaps less relevance for digital preservation.

- *Are the requisite technical skills for implementing instances of the information system type available to organisations?* Each technology development may require the development of new or enhanced skills to use or fully benefit from the development. The availability of skills may encourage the implementation of a technology development and the absence of skills might inhibit its implementation.[18]
- *How invested are organisations in existing types of information systems, i.e., legacy systems?* A legacy system is one that may have been designed using a previous generation of information technology and may still reply upon that technology. The degree of reliance upon existing information systems and the compatibility of the new information system type with existing or legacy information systems would influence the acceptance of the new type.

In addition to providing a framework for the assessment of the specific technology development based on the analysis of the larger technology category, these questions could also be used in continual monitoring to detect the emergence of future types of information systems.[19]

The *analyse* step studies the technology development then uses the evaluation criteria provided by the scope step to frame the investigation of the technology development. The analyse step would develop a characterisation or profile of the technology development as a foundation for understanding the technology development that has value on its own for technology responsiveness and as an explicit contribution to the evaluation of the technology development. For example, an object-based system reflects the capabilities afforded by its adherence to the principles of object-oriented programming, including the ability to:

[18] Section 3.6 discussed the human response to technology, noting the impact that reluctance or enthusiasm to use a new technology can have on the emergence of technology.
[19] For example, indicators of a new type of information system might include items that describe the development of a new data model, promote the capabilities of a new programming language, or announce an extension in the capabilities of common computer environments.

- define the digital content by its essential characteristics (*abstraction*),[20]
- manage digital content as a cohesive unit with defined behaviours (*object*),[21]
- perform generic and specialised operations (*methods*),[22]
- group objects logically and allow common methods for groups (*class*),[23]
- pass characteristics or traits from one object or class to another (*inheritance*),[24]
- package the methods and content together (*encapsulation*),[25]
- use methods defined for objects and classes to enable objects from different classes to respond to the same request differently (*polymorphism*).[26]

For digital preservation, these abilities offer the potential for an object-based system to manage digital content, to apply digital preservation policies, and to accumulate information about digital preservation events over time.[27]

Examples of responses to the evaluation criteria questions identified in the scope step for object-based systems would be:

- *Do programming languages exist that can implement the information system type?* Programming languages that enable the implementation of

[20] By using only characteristics that are relevant to the purpose, abstraction reduces complexity because the details about the content are stored within the objects allowing the digital content to be managed generically as objects, regardless of the specific type of content in each digital object. Ivar Jacobson is an authoritative object-oriented researchers and developers who began working on object-based systems in the 1960s. Jacobson, *Object-Oriented Software Engineering*, 49.
[21] Jacobson defines an object as "an entity able to save a state (information [or digital content]) and which offers a number of operations (behaviour) to either examine or affect the state". Jacobson, *Object-Oriented Software Engineering*, 44.
[22] A method describes a behaviour that an object is able to perform. Jacobson, *Object-Oriented Software Engineering*, 44-45.
[23] "A class is a definition, a template, or a mold to enable the creation of new objects and is, therefore, a description of the common characteristics of several objects." Jacobson, *Object-Oriented Software Engineering*, 50.
[24] With the use of inheritance, "common characteristics can be shared by several classes…we can reuse descriptions". Jacobson, *Object-Oriented Software Engineering*, 56-57 .
[25] Encapsulation means that "all information stored within an object-oriented system is stored within its objects and can only be manipulated when the objects are ordered to perform operations". Jacobson, *Object-Oriented Software Engineering*, 48.
[26] "Polymorphism means that different *instances* [an object created from a class] can be associated, *and* that these instances can belong to different classes." Jacobson, *Object-Oriented Software Engineering*, 50, 55.
[27] For example, to invoke a digital preservation plan to migrate some portion of digital content in an object-based system from one format to another. To do that, a digital curator might define a method to which only digital objects containing content stored in the specified format could respond.

object-based systems exist and are increasingly used for information system development.[28]

- *Does a data model exist for the information system type that is ready to be implemented?* The object data model has been defined and, although the model emerged significantly after the principles for object-oriented programming were defined, a feature of object-oriented design is that it can be used to implement any kind of system. [29]
- *Can the information system be implemented on common, contemporary computer platforms?* Compatibility was often a barrier to the implementation of object-based systems into the 1990s. Object-based systems became more feasible with developments in storage processing capacity, network capacity, and complex digital object management, and even more so as more object-based systems were implemented.[30]
- *Are the requisite technical skills for implementing instances of the information system type available to organisations?* The concepts of object-based systems are complex and have sometimes been viewed as difficult. Increased awareness and understanding of the concepts will encourage the use of object-based systems.
- *How invested are organisations in existing types of information systems, i.e., legacy systems?* The continued dominance of relational systems has been a deterrent to broader implementation and use of object-based systems, although the implementation numbers for object-based systems are

[28] The principles of object-oriented programming were defined in the 1960s, although programming languages capable of implementing the principles did not emerge until the 1990s. Programming languages for object-oriented programming developed first through extensions to existing programming languages, e.g., C++, then object-oriented languages, e.g., Java and Python. See for example: Carlo Ghezzi, and Mahdi Jazayeri, *Programming Language Concepts*, 3rd ed. (Chichester: Wiley, 1998), 9; and Connolly, Begg, and Strachan, *Database Systems*, 783.

[29] March and Smith noted that "posing a new database design model may be a significant contribution; however, to inform researchers in the field, the new model must be positioned with respect to existing models". March and Smith, 'Design and Natural Science', 261. Object-oriented programming principles and the relational model both emerged in the 1960s. By contrast to object-based systems, the relational model was the first data model to be formalised for an information system. March and Smith, 'Design and Natural Science', 260.

[30] The announcement of dbo4 stresses that the new version overcomes what had been a barrier to the use of object-based systems. dbo4 objects, 'db4o Version 6 Debuts ', http://www.db4o.com/about/news/release/2006_11_14.aspx?AspxAutoDetectCookieSupport=1 (accessed 25 May 2008).

increasing.[31] Object-relational systems are a compromise implementation that acknowledges an organization's commitment to relational systems and allows the strengths of object-based systems to be incorporated.[32]

The application of the evaluation criteria to object-based systems reveal an emerging technology that is increasingly used, but not yet at its peak of implementation.

There are two additional topics that an evaluation of object-based systems would identify. First, if relational systems are so widely used and have dominated the market for such a long time, why would new systems be of potential interest? Comparisons of relational and object-based systems are quite common in the literature. The ability of object-based systems to mange complex and homogeneous digital content at a greater scale than relational systems is the most often mentioned reason for the emergence of object-based systems.[33] Second, if the relational model and object-based programming both emerged in the 1960s, why did relational systems emerge so much more quickly than object-based systems and dominate the market for such a long time? Authors provide various explanations, but a common thread is that the most commonly-used technologies were better suited to relational than object-based systems and initial object-based developments had very specific applications (e.g., scientific simulations) and relational systems were broadly applicable (e.g., financial transaction systems).[34]

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[31] The market for relational software products continues to increase. See for example: Gartner, Gartner Says Worldwide Relational Database Market Increased 14 Percent in 2006, press release, http://www.gartner.com/it/page.jsp?id=507466 (accessed 25 May 2008).

[32] See, for example: Behrooz Seyed-Abbassi, 'Object Oriented Relational Database with SQL Interface', In Proceedings of the 1993 ACM Conference on Computer Science, Indianapolis, Indiana, February 16-18, 1993, 497-504; Arthur M.Keller, Richard Jensen, and Shailesh Agarwal, 'Persistence Software: Bridging Object-Oriented Programming and Relational Databases', ACM SIGMOD Record 22, no. 2 (1993): 523-28; and Ramakanth S.Devarakonda, 'Object-Relational Database Systems - The Road Ahead', Crossroads 7, no. 3 (2001): 15-18.

[33] Mannila also noted that new applications, e.g. Computer-Assisted Drawing (CAD), require better data modelling facilities than relational offers (a strength of object-based systems) and relational does not support modular design (a feature of object-based systems). Heikki Mannila, and Kari-Jouko Räihä, The Design of Relational Databases. Wokingham: Addison-Wesley, 1992, 60.

[34] In 1978, Backus identified the limitations of the most common computers that used a basic three-part structure introduced by von Neumann in the 1940s consisting of a central processing unit (CPU), a store (to hold the content), and a tube to transmit a word at a time from the CPU to the store. The relational model (that stores content in rows and columns in which each cell is identifiable) could be implemented within the constraints of the von Neumann architecture more readily than object-oriented programming (which relies on the transmission of packages of

The *evaluate* step uses the results of the first three steps of the assess stage to study the technology development and to identify the implications of the technology development for digital preservation and to provide recommendations to maximise the opportunities and limit the negative impacts it presented. The evaluate step identified two increasingly familiar examples of object-based design and implementation with the digital preservation community: the Open Archival Information System (OAIS) Reference Model (an example of object-based design) and the Fedora repository (an object-based and open source repository software package that organisations use to manage digital content). [35] The most positive implication of object-based systems is the ability to package digital content in a protective wrapper, including its essential metadata, and to manage those objects using documented rules. These are capabilities which address the integrity features for digital content as discussed in Section 2.7. Another positive implication is the ability of object-based design to communicate the requirements for digital preservation to external communities.[36] The most negative implication of object-based systems is that object-based concepts are difficult to understand.[37] Another negative implication is that the potential impact of the wider use of object-based

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information). Backus proposed Algol, an early object-style programming language as a means to break out of the 'bottleneck' created by the von Neumann architecture. Backus, John, 'Can Programming be Liberated from the von Neumann Style? A Functional Style and its Algebra of Programs', Communications of the ACM 21, no. 8 (1978): 615, 620, 635. See also: Ghezzi and Jazayeri, *Programming Language Concepts*, 9, 22-23.

[35] OAIS and Fedora are object-based because each conforms to the characterisation of object-based systems defined earlier in this section: objects are defined by their essential characteristics (abstraction), digital content is managed as cohesive units (objects), objects are able to respond to defined operations (methods), objects are able to be grouped (class), traits are able to be passed from one object or class to another (inheritance), objects include methods and content (encapsulation), and methods are defined so that objects from different classes are able in different ways to the same request (polymorphism).

[36] The communication potential of object-based design could be used to raise awareness, to educate, to inform, to plan preservation strategies, and to demonstrate the potential effects of proposed strategies. The OAIS Reference Model provides an example of the ability to convey digital preservation concepts across divergent communities. OAIS also provides an example of how object-based design could be used as a technology transfer model for preserving digital content contained in information systems that are not object-based. An object-based reference model could be defined for any existing system with annotations to illustrate digital preservation requirements to demonstrate to the systems creators how the content of the system might be preserved. The OAIS Reference Model document identifies its intent to provide a framework and terminology for comparing aspects of OAIS system implementations across organisations. CCSDS, *OAIS Reference Model*, 1-1.

[37] The digital preservation community faces a challenge in making effective use of object-based design concepts and this may limit the spread of object-based systems, although OAIS and Fedora are indicators that an understanding of object-based concepts is increasing within the digital preservation community.

systems, as an emerging technology, remains uncertain.[38] The analyse step for this technology assessment of object-based systems might recommend finishing the technology assessment as well as continuing the monitor stage while object-based systems continue to emerge.

The evaluate step for object-based systems would produce these kinds of recommendations for the digital preservation community regarding the technology development for use in formulating an appropriate responses:

- Explore the potential of object-based systems for preserving digital content in existing information systems and for developing object-based preservation systems.
- Include object-based concepts in digital preservation curriculum to raise awareness about object-based systems.
- Test the application of object-based design for preserving digital content in existing systems and for effectively extracting objects from other types of systems.
- Define triggers for monitoring technology developments pertaining to object-based systems, e.g., further increases in the use of object-oriented programming languages and the market share for object-based software and the availability of fully object-oriented software packages.
- Identify and track examples of the use of object-oriented programming for generating AIPs.
- Develop a test bed for exploring and testing object-based design for digital preservation.

[38] The development of object-relational systems, the relatively slow increase in fully object-oriented systems, and the continuing strength of relational systems in the market open a range of possibilities for the future. This potentially negative implication is offset by a strength of object-based systems in that investing in object-based systems would not preclude moving to other types of information systems; the results of the investigation demonstrate that object-based concepts are quite flexible in that aspect.

In addition to producing digital preservation recommendations, the evaluate step would be likely to identify related or additional technology developments of potential interest for digital preservation.[39]

A technology assessment may be terminated before the evaluate step and returned to the monitor stage with the possibility of being repeated when further development of technology warrants. Reasons to terminate an assessment include the lack of core or enabling technologies that might allow the technology development to move from the innovation to the diffusion stage of innovation, the detection that a technology development that will supersede the technology to be assessed, or the detection that milestones pertaining to the emergence of the technology that are on the verge of occurring, suggesting that deferring the technology assessment would be worthwhile. Evidence that existing programming languages were incapable of implementing the type of information system being evaluated would be sufficient to defer the remainder of the technology assessment and to monitor for specific programming language developments.

5.7 Respond Stage

The *respond* stage formulates and implements suitable responses to technology developments using the results of the assess stage. The respond stage includes three steps: formulate, measure, and adjust. Once the assessment is completed, it should be possible for the community and its members to develop informed and appropriate responses to technology developments.

The *formulate* step develops responses, including community guidance, the promulgation of standards, new or revised preservation strategies for organisations, evaluations of the results by individuals and organisations, technology transfer

[39] This benefit of evaluation is noted by: March and Smith, ‘Design and Natural Science’, 263. For object-based systems, an example of a technology development that and might be nominated for continual monitoring and possible technology assessment include semantic programming, especially pertaining to the web. See for example: E. Eessaar, 'Preserving Semantics of the Whole-Part Relationships in the Object-Relational Databases', in Advances in Information Systems Development: New Methods and Practice for the Networked Society Chap. 1 (Springer US, 2007), 1-11.

examples, and proposed research topics. The recommendations produced by the assess stage (see Section 5.6) provide the basis for the responses.

A technology assessment might also recommend a risk assessment of digital content that relies upon existing technology if the findings suggest that the underlying technologies might be affected by acceptance of the technology assessed.[40] The need for a risk assessment was not identified for the object-based example because object-based systems continue to supplement rather than supersede existing systems. In addition, the strengths of object-based design and the characteristics of object-based systems suggest that it should be possible for object-based systems to incorporate content from most other types of information systems rather than isolating the digital content in obsolete systems.

The *measure* step evaluates the impact and outcomes of digital preservation responses to technology. In measuring outcomes of a response, possible considerations include the extent of digital content potentially affected by the response, e.g., distribution by quantity, type, and size; the extent of organisations applying the response, e.g., distribution by type, geography, and sector; and the identification of potential benefits and negative impacts of applying the response, e.g., detected loss or impairment of digital content or its associated behaviours. An interesting approach for measuring the impact of developments within a community is the Registry of Open Access Repository Material Archiving Policies (ROARMAP).[41] This approach could be applied within the digital preservation community to achieve the measure step of the technology response model to look for indicators that digital repositories are modifying their practice in ways that are able to be detected, for example. It might be possible to determine that repositories are adopting recommendations based on the explicit use of a particular policy, for example.

[40] This was initially reflected in Figure 4-1 in Section 4.2 as "act to avoid negative impacts on existing technologies" then integrated into the respond stage of the model.
[41] ROARMAP, 'ROARMAP (Registry of Open Access Repository Material Archiving Policies (ROARMAP)', *eprints.org*, http://www.eprints.org/openaccess/policysignup/ (accessed 25 May 2008).

The *adjust* step modifies the response formulated for the technology development using the results of the measure step. As accepted practice regarding object-based systems is extended and formalised, information about examples of policies, procedures, and implementations would be accumulated by the monitor stage and would inform adjustments to the response to object-based systems. Eventually, a response to a technology development is incorporated into common practice.

5.8 Consolidating Technology Response Results

At each stage of the technology response model, results are produced, as illustrated in Figure 5-1.[42] The accumulated results would then be available for monitoring and analysis as an individual technology development evolves. All of the information about a technology development would also be available as it pertains to the study and analysis of other technology developments.

The example reviewed in this chapter provided samples of the types of results that would be produced when the stages of the model are applied to an individual technology development. Figure 4-10 illustrated the model by focusing on the relationships between the stages of the model with cursory examples of results. Figure 5-1 focuses more specifically on the results produced by applying the model. The diagram suggests the types of results for each stage that would be accumulated in a store of information about technology developments maintained by the monitor stage. It also emphasises the temporal aspects of the technology response process by mapping the innovation stages to the model's stages. Ideally, as discussed in Section 4.2, a technology development would be detected as early as possible during the invention stage then monitored and assessed during the innovation stage with a response ready before diffusion begins. As the model is applied to many technology developments, the accumulated content will echo the development paths of all of the selected technology developments, providing a landscape of technological change for digital preservation.

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[42] The diagram in Figure 5-1 was developed by the author of this thesis to illustrate the accumulation of results from applying the technology response model.

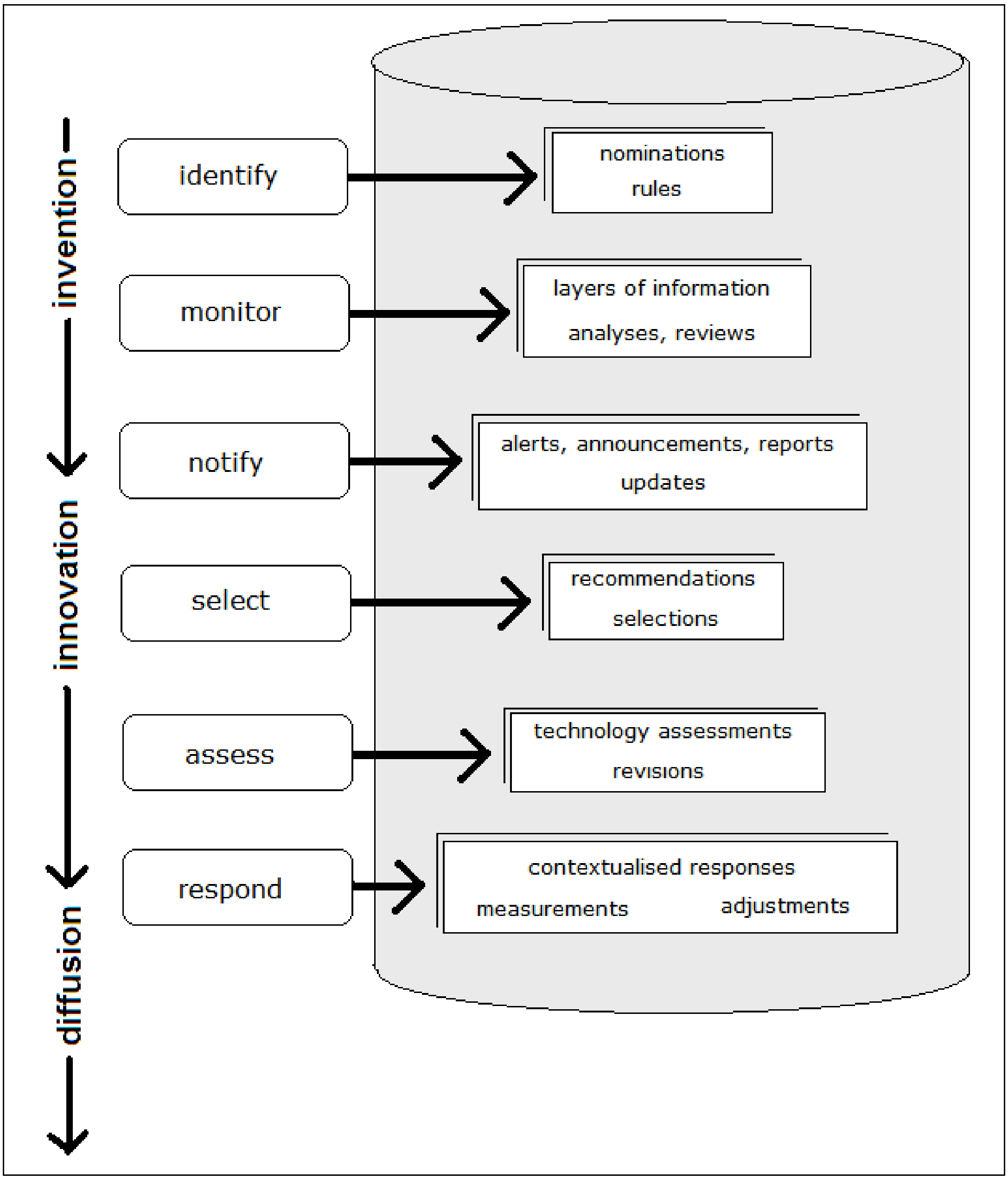

Figure 5-1. Sample results and timing of the stages.

5.9 Conclusion

This chapter illustrated the application of the technology response model to a complex technology development with potential implications for digital preservation: object-based systems. The technology response example provided output samples to illustrate the results produced by the stages and identified challenges encountered in completing the stages. As stated in the chapter's introduction, the primary purpose of the example was to validate the model. The example provided a valuable and informative examination of the model. Section 6.3

discusses the results of the formal evaluation of the model, beyond those already discussed in this chapter, using established metrics for the evaluation of models.

As noted in Section 5.2, object-based systems would be immediately matched to the repository and object categories of the technology framework. Once implemented, it would be common for the model to link a technology development to a single category of the technology framework or item on the technology inventory at the start, due to the initially limited awareness of the technology development, and for additional linkages to be identified as all of the stages are completed. A deeper understanding of a technology development with a comprehensive assessment of its possible implications through the application of all of the stages might uncover previously undetected connections to the framework and inventory, making the technology development even more significant than the earlier detection might have indicated. The analysis in the assess stage would identify other connections to the technology framework and technology inventory. In the object-based systems example, connections to other technology framework categories (collections, standards, and competencies) and to the potential role of object-oriented programming, an enabling component of object-based systems, would be examined and addressed. Implementing the model would enable the digital preservation community to not only be aware and prevent negative impacts of a technology development – the most familiar responses within the digital preservation community – but also to exploit and adapt it for preservation purposes – the less familiar responses discussed in Chapter 3.

The ability for the digital preservation community to detect, monitor, assess, and respond to technology development with potential implications for digital preservation is the essence of technology responsiveness for digital preservation. The intended outcome of implementing and sustaining the technology response model is to identify an appropriate set of technologies to monitor for assessment and response, to deepen the understanding of relevant technology developments within the digital preservation community, to raise awareness within the community about technology responsiveness in general, and to enable the community to respond effectively to the cumulative set of relevant technology developments that reflects technological change from a digital preservation perspective.

Chapter 6. Conclusion

6.1 Introduction

This thesis has discussed the investigation of technology responsiveness for digital preservation and the resulting technology response model to enable technological responsiveness for digital preservation. The research included an investigation of technological change (Chapter 2), an evaluation of technology responses to determine an optimal approach for digital preservation (Chapter 3), the delineation of the functions and content of the technology response model (Chapter 4), and a technology response example that illustrates the application of and validates the logic of the model using object-based systems as (Chapter 5). This chapter reviews the research questions, evaluates the technology response model for digital preservation, examines issues pertaining to its implementation by the digital preservation community, discusses future research on technology responsiveness, and provides a set of recommendations for achieving technology responsiveness within the digital preservation community.

6.2 Revisiting the Research Questions

These questions framed the research (see the discussion in Section 1.2 where the questions were introduced):

How would developing an understanding of the nature and cycle of technology developments contribute to the definition of a scope of interest in ongoing technological change that is appropriate to digital preservation objectives? The need for the digital preservation community to respond to technological change has been acknowledged, yet the concept and characteristics of technological change have not been discussed previously to any extent in the community's literature. The investigation determined that technological change is the cumulative result of overlapping and interrelated technology developments. Using the innovation cycle as a set of guideposts allows an individual technology to be detected and tracked within the overall context of technological change. This perspective will enable the digital preservation community to document and measure its response to technological change.

Developing a deeper understanding of technological change led to several results that allowed the scope of interest in technology developments for digital preservation to be examined and adjusted, as discussed in Chapter 2. The technology framework defines a higher-level framework with six major categories (object, collection, repository, platform, organisation, standards, and competencies) that expands beyond a focus on file formats to a more comprehensive scope of interest in technology developments for digital preservation. The framework also provides a context for mapping technology developments for systematic study. The technology inventory refines the scope of interest with a list reflecting the technologies and functionalities which enable the functions of the OAIS Reference Model, a core standard of the digital preservation community. The investigation also developed a means to prioritise technology developments to invest the energies of the digital preservation community in the study and evaluation of the most significant technologies. The research proposed a process for adjusting the scope as technology evolves. The discussion of sources of information about technology developments considers the role and value of the major categories of sources for understanding and determining the implications of technology developments for digital preservation. Together these results address which technologies to be concerned about for digital preservation and how to detect and prioritise related technology developments.

How have communities responded to technological change and to what extent are existing models and examples of technology responsiveness effective for digital preservation? The extent of the digital preservation community's response to technological change is traced in Section 1.5 and the responses to technology by other communities are the focus of Chapter 3. The research indentified four major technology response types: technology forecasting to exploit the potential gains offered by technology developments, technology assessment to avoid potentially harmful impacts of technology developments, technology transfer to encourage the reuse of a technology development across domains, and technology monitoring to enable awareness of technology developments. Although each technology response type has substantial literature (or implemented examples in the case of technology watch services for technology monitoring), there has been little or no substantive discussion of them within the digital preservation community, let alone any systematic study of the technology response types. No such study was identified in other communities whose results could be applied to digital preservation. The significance of the human response to technology was considered, noting the need for continual learning to address new technologies. An important aspect of the human response is how the acceptance of or reluctance towards new technologies by users of technology affects whether and when technology developments become widely used.

What approach could be devised for use by the digital preservation community to continually detect, evaluate, and respond to technology developments that have potential implications for the long-term preservation of digital content? The investigation of the technology response types suggested that combining the four responses would enable a comprehensive response to technology for digital preservation. The technology response model for digital preservation incorporates the techniques and outcomes of the four technology responses into its stages and results. The mapping of the stages of the innovation cycle noted where in the cycle the techniques to detect and track technology developments would be applied. The points at which detection, evaluation, and response should occur were noted, using the results of continual monitoring. This mapping informed the definition of six technology response stages: identify, monitor, notify, select, assess, and respond. The stages of the model would be iteratively applied from the point at which a technology development is detected. The first three stages would be applied to all technology developments of potential interest. The other stages would only be applied to technology developments that are determined to be most relevant for digital preservation and that warrant a technology assessment at a particular time.

The specification of the technology response model defines the inputs and outputs of the steps within each stage and the interactions between the steps and the stages. The specification also defines a content model for technology response that includes the accumulation of unprocessed information, or data, about technology developments within the scope of interest for digital preservation; processed information produced by analyses of the data to generate alerts, reports, and updates; and the results of technology assessments and other systematic investigations of technology developments that are most relevant for digital preservation.

These components of the technology response model for digital preservation applied in a systematic and sustained manner would allow the digital preservation community to continually detect, evaluate, and respond to potentially relevant technology developments. Cumulatively, technology developments amount to technological change. The model would enable the digital preservation community to meet its acknowledged need to respond to technological change.

How might the potential implications of the emergence of technology developments be determined and evaluated to develop responses that are appropriate to the technology development? The technology response example, object-based systems, included samples of the results produced by the assess stage and the respond stage of the model. The assess stage formalises an evaluation process by one or more assessors that results in a technology assessment of the technology development for digital preservation. The technology assessment includes recommendations for responding to the technology development based on the potential implications of the technology development for digital preservation as determined by the assessment. The respond stage defines three steps that would be undertaken at the community, organisational, and individual level. The steps formulate a response to the technology development based on the recommendations, measure the impacts of the response for as long as the response is in use within the digital preservation community, and adjusts the response as needed based on analyses of the metrics used to measure the impacts of the response.

The monitoring stages of the model (identify, monitor, and notify) ensure that technology developments within the scope of interest for digital preservation are detected and tracked. The assess stage determines the implications of the technology development for digital preservation. The respond stage enables the responses to be adapted to specific contexts and the outcomes of the responses to be measured. This sequence allows technology responsiveness for digital preservation to be appropriate and timely.

Applying the model to object-based systems proved to be challenging and informative. Information systems are a complex type of information technology and, as discussed in Section 1.5, complex technologies are not generally addressed by existing responses to technology in the digital preservation community. A consideration in using technology response examples to evaluate technology developments is that technology assessments address the characteristics, strengths, limitations, status of, and recommendations pertaining to a particular technology development at one moment, valid until the technology response model detects the need for anew or revised technology assessments. Given that technology changes continually, the results of technology assessments will have to be revisited periodically.

The literature of the digital preservation community has lacked substantive discussions of technology, as the literature review concluded in Section 1.6, and has lacked the means for sustained and systematic reviews of technology-related literature. The absence of discussions of technology and access to information about technology has meant that digital curators may be unfamiliar with the terminology, concepts, and methods used in relevant technological fields. The proposed technology response model for digital preservation addresses this community need by providing the means to raise awareness within the community about relevant technology developments and to inform community members about technology developments of interest. The implementation of the model for the digital preservation community would provide these services by analysing a comprehensive accumulation of available information about technology developments.

Researchers in the computer science, information technology, management, and other domains use constructive research to develop solutions to problems. The methodology includes an evaluation of the logic and comprehensiveness of the resulting solution. Constructive research can be used for individual, team-based, or community-level research. Constructive research methodology provided a structured process for producing the technology response model. The methodology and the model were developed for digital preservation, but both would be easily adaptable for the study of other parts of the digital content life cycle, e.g., appraisal and selection, description, access services and reference. Although some kinds of digital content have been preserved for several decades, the digital preservation community is still emerging as a cross-domain collaborative group, as discussed in Section 1.4 and the scope and practice of digital preservation research is at a formative stage. The research showed how constructive research could be applied to the exploration of new areas as technology and requirements evolve.

6.3 Evaluating the Technology Response Model

The final step of constructive research methodology is to examine the applicability of the solution proposed by the research, i.e., the technology response model for digital preservation. Proponents of a methodology for evaluating models have defined a set of five metrics: fidelity with real world phenomena, completeness, level of detail, robustness, and internal consistency.[1]

The first evaluation metric tests the model for *fidelity with real world phenomena*. Fidelity for models is defined as “the accuracy of the representation when compared to the real-world”.[2] In this research, technological change is the phenomenon studied. Technological change results from an ongoing series of interrelated technology developments, as shown by the research discussed in Chapter 2. The technology response model reflects the natural occurrence of technological change by allowing technology developments to be detected, monitored, assessed, and addressed as individual developments as well as in relation to other developments. Users of the technology response model can explore

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[1] The research steps for constructive research were discussed in Section 1.8 and the Chapters of this thesis mapped to those steps. March and Smith identified the absence of metrics that are appropriate to the four types of research outcomes that constructive research might produce: constructs, models, methods, and instantiations. These are the metrics they proposed for evaluating models. March and Smith, ‘Design and Natural Science’, 261.

[2] U.S. Department of Defense (DoD), ‘Modeling and Simulation (M&S) Master Plan’, DoD 5000.59-P, Under Secretary of Defense for Acquisition and Technology, (Washington, DC: Department of Defense, October 1995), A-5.

technologies through active engagement with the accumulated information about the technologies. Users can also become aware of technologies through more information services, sharing, and exchange provided by an implementation of the model. The model provides the digital preservation community with the tools and the context for exploring technological change.

The *completeness* metric considers if a model has all of its necessary parts or components. The investigations of technological change and technology responses provided the building blocks for and informed the construction of the model. For example, the technology watch examples surveyed accumulate information, but none offer easy access to that information; such access was noted as a requirement for the technology response model. The technology response example, object-based systems, tested the completeness of the model and no gaps were revealed in its stages and steps. The example provided a conceptual validation of the model to check its logical cohesion and comprehensiveness. A full practical demonstration would be inherent in an implementation of the model by the digital preservation community. References to existing tools and practice throughout the thesis also show that requisite functionality and tools exist that could be adapted for or incorporated into an implementation of the model.

The *level of detail* of a model refers to the degree of specificity provided about the phenomenon the model addresses. This metric is sometimes referred to as the model's granularity.[3] The technology response model includes two levels of granularity: high-level stages with lower-level steps for each stage. The definition of the model in Chapter 4 also identifies the inputs to, outputs from, and interactions between the steps and stages. The model's level of detail proved sufficient as shown in the example of a complex technology development, object-based systems.

Durability and adaptability are two commonly-cited characteristics of *robustness*.[4] For the technology response model to enable technology responsiveness as technology evolves, it must indeed be durable and adaptable. The

[3] DoD, 'Modeling and Simulation (M&S) Master Plan', A-7.
[4] Robustness refers to the strength of the model to address planned and unplanned events.

technology response model is intended to be generally applicable to technology rather than specific to certain categories, so it has some inherent adaptability. The technology framework and technology inventory (discussed in Sections 2.5 and 2.6) were developed to make the digital preservation scope of interest adjustable to new and changing technologies, making the model both adaptable and durable through the course of developments. Testing the technology response model on the challenging example of object-based systems tested its durability and verified the feasibility of extending the digital preservation response from simple to complex technologies.

Within the model, the pieces need to be *internally consistent*. The model definition should address ambiguities. The iterative process of the steps within the stages and of the stages themselves provided a test in completing the technology response example of the technology response model's internal consistency. For example, the initial definition of the accept step in the identify stage included a consideration of the priority score for the technology. It became clear in the object-based systems example that the priority score should be associated with the recommend stage of the select stage rather than the accept step of the identify stage because there might not be enough information about the technology at the start of continual monitoring to determine a priority score, e.g., the technology might only be associated with a category of the framework and not yet linked to technologies on the inventory that would have a score. Completing the technology response example illustrated the sequence of steps for adjusting the scope of interest in technology developments for digital preservation that was discussed in Chapter 2. Being inclusive at the identify stage will allow potential technologies to be identified and considered. Being more exclusive at the select stage, once adequate information is available about a technology developments, will ensure that only the most relevant developments are studied intensively.

Using object-based systems to validate the technology response model tested its applicability to a complex example. The technology response process defined by the stages of the model was applied sequentially to simulate a process that would occur over a variable period, beginning when with the detection of a technology development and continuing until its obsolescence or abandonment. The duration of that period would be determined by the stages of the innovation cycle of individual technology developments. The technology response example in Chapter 5 and this evaluation document that the model provides a solution to the problem of responding to technological change for digital preservation. Once the model is fully implemented within the community and maintained for some time, the instantiation of the model (one of the four possible products of constructive research) would then be evaluated. The evaluation metrics for an instantiation, as defined by constructive research methodology, include a consideration of its efficiency and effectiveness and an assessment of its impact on the user community.[5]

6.4 Implementation Considerations for the Model

Implementing the technology response model for the digital preservation community will be challenging, but there are achievable objectives and examples to build upon. From a tactical perspective, implementation will involve identifying, developing, applying, and testing the tools and techniques to iteratively and comprehensively gather, process, and analyse information about technology developments with relevance for digital preservation. From a feasibility perspective, a sustainable implementation will involve defining practical economic approaches, identifying incentives for participation and support, and achieving and maintaining broad-based support within the community. This section first examines a successful community-based repository example to identify success factors that might be relevant in implementing the technology response model then addresses a set of implementation issues informed by those factors.

ArXiv is a pre-print repository now hosted by Cornell University that was established in the early 1990s by and for the physics community.[6] It has since expanded to include the major science and math communities. It is a community-supported repository that has been in operation over several generations of technology. It benefited from global expansion of the World Wide Web, for example. Although an implementation of the technology response model would have more heterogeneous content than ArXiv and would provide more complex

[5] March and Smith, 'Design and Natural Science', 261.
[6] The ArXiv repository Web site is available at: http://arxiv.org/.

services than delivering content, as ArXiv primarily does, both represent repositories dependent on community support to be sustainable. There are lessons to be learned by studying the success of ArXiv. Kenney has suggested a series of success factors for ArXiv.[7] ArXiv has the strong commitment of an international scholarly community that can be measured by continuing contributions to and increasing use of the repository's content. Authors who contribute to ArXiv accept responsibility for most of the ingest effort making the accumulation of content an affordable and manageable process. The scholars in the ArXiv communities require continued access to the content so they are supportive of the preservation of the content. Most of the processes to get content into and out of ArXiv as well as the management and maintenance processes are automated reducing the need for costly human involvement. ArXiv accepts a limited number of stable formats and relies upon simple forms of migration for its preservation planning, further reducing the potential management overhead for ArXiv. Finally, the accumulation of ArXiv content serves an important and valued role for the timely and comprehensive sharing of information within the scholarly communities that contribute to ArXiv that supplement and possibly substitute for formal scholarly products within those communities.

Briefly stated, ArXiv is successful because it is valued by its community, serves an important function for the community, addresses the needs of its contributing communities, and is easy to maintain. ArXiv is an integral part of those communities, not a separate initiative for which incentives must be sought to support it. The scholarly communities that are served by ArXiv show a great interest in ongoing access to its content and would rally in support if it were at risk of failing or declining. These success factors informed the discussion of implementation issues for the technology response model. The categories of implementation issues considered in this section include research and development activities, sustainability, community engagement, and competencies.

[7] Anne Kenney, University Librarian at Cornell University Library and co-developer with the author of this thesis of the Digital Preservation Management workshop series, previously cited in this thesis, presented a case study on ArXiv within her resources presentation for the workshop. Anne R. Kenney, ‘Identifying and Securing the Requisite Resources’, Digital Preservation Management workshop presentation, 2003-2007.

Implementing the technology response model would involve the completion of an iterative sequence of *research and development activities*:

- defining and testing triggers to detect information technology developments that are potentially significant for digital preservation;
- adapting text mining and pattern analysis techniques for automatically gathering and analysing information;
- defining and applying policies, procedures, and tools for storing and accessing information about technology developments;
- developing templates for automatically capturing and annotating items of interest about technology developments;
- creating tools for generating and managing alerts within and beyond the digital preservation community;
- developing the outputs of the notify and assess stages and testing the outputs with users; and
- defining guidelines for sharing information with technology responsiveness implementations in other communities.

Completing these activities would combine the expertise from the digital preservation, computer science, information science, and other communities. A primary objective of these activities would be to replicate the successful ArXiv approach by developing automated processes within a technology infrastructure that is manageable, affordable, and relatively easy to maintain. Members of the digital preservation community could undertake these activities through collaborative projects with ongoing institutional support, possibly benefiting from initial or periodic grant-funded support.

The *sustainability* of an implementation of the technology response model is essential. The survey of technology watches showed that some examples had already ceased operation. In the case of DigiCULT, for example, the grant-funded project ended and the technology monitoring activity was then not sustained. The ArXiv example proves that a technology-based implementation that serves a community's needs can be implemented and maintained for an extended period of time with the active support of that community. In the case of the technology response model, the implementation could contribute to its own sustainability because the model itself would detect technology developments to enable and enhance technology responsiveness. For example, the functionality of the send step maps to messaging and procedural protocols on the technology inventory. This would ensure that the technology response model remains compatible with contemporary technology and therefore, accessible to users. The technology response model itself would benefit from the implementation of the technology response model. In addition, the possibility of distributing the implementation across the community should mean that many organisations and individuals are able to contribute to its maintenance, enhancement, and evolution. This should increase the likelihood of success by encouraging active participation and support and reduce the possibility that the departure of a single participant could lead to the failure of the implementation.

Sustained technology responsiveness will require *community engagement*. ArXiv shows that if the community values the services provided and appreciates the outcomes enabled by the implementation of the technology response model, the community will be more likely to participate in sustaining the implementation. Community engagement might be measured by the willingness of members to contribute and to annotate content pertaining to relevant technology developments, to devise tools and procedures for harvesting then managing accumulated content, to contribute their expertise to the assessment of technology developments, and to utilise the content to understand and respond to those developments. The relative concentrations of participation for the three core components of technology responsiveness – *monitor*, *assess*, and *respond* – are illustrated in Figure 6-1. Any and all members of the digital preservation community could and should contribute to and benefit from monitoring activities. Even if no assessments were conducted, monitoring would raise awareness about relevant technology developments and contribute to an increasing understanding within the community of those developments. A subset of the community would participate in the assessment of relevant technologies as determined by the completion of the stages and steps of the model and based upon their skills, interests, knowledge, and availability. Developing and retaining the interest of a set of trained and experienced assessors would contribute to the success of the implementation. Any and all members of the community might be involved in the development and application of responses based upon the understanding and recommendations derived from the results of the monitor and assess components. The responses would be adaptable to the specific expectations and requirements of the context in which the responses are applied. This might result in a number of versions or iterations of the responses to be responsive across the whole of the community. Individual and organisational members would determine their level of involvement in the monitor, assess, and respond components. Participating organisations might include digital repositories, professional societies, academic institutions, technology vendors, standards developers, and funding bodies for research and development.

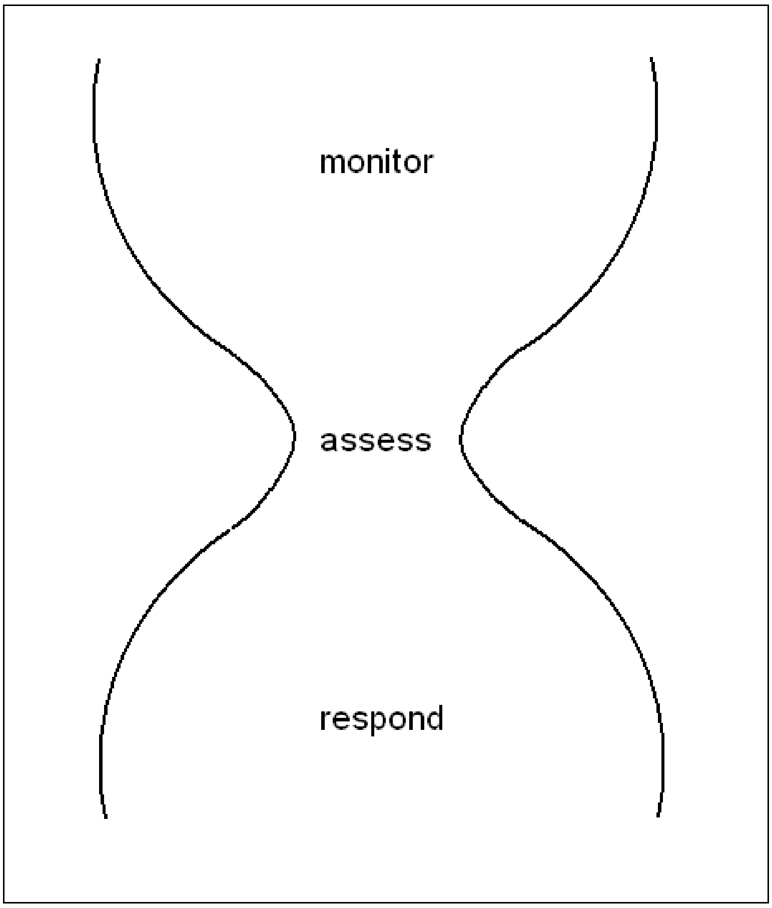

Figure 6-1. Hourglass model of technology response participation.

There are specialised roles to be performed by community members within the three components of technology responsiveness. For ArXiv, the community roles performed include producers, or authors, of pre-print articles; reviewers, who apply criteria for inclusion and monitor content for each topical areas; users of the content, who use ArXiv to track developments in their community and to find and utilize the stored content in a variety of ways; and system managers, who maintain and enhance ArXiv. The community roles for technology responsiveness were identified in Section 4.4 as contributors, content and service managers, assessors, responders, and users. These technology responsiveness roles would have to be further specified and filled by members of the community. For example, a technology assessment team ideally would combine organisational and technological skills, and would have access to supplementary skills, e.g., legal and financial, as the need emerges during the technology assessment. The managers of the implementation of the technology response model would encourage individuals with relevant skills and interests to volunteer to be assessors and could actively identify potential assessors by matching skills with technology developments as each are detected. Implementing continual monitoring as a distributed function would allow many organisations and individuals to participate in and contribute to the development and maintenance of technology responsiveness for digital preservation. The success of ArXiv suggests that members of a community are willing to serve these roles and to contribute to ongoing management, if they value the content and service provided.

In terms of use, members of the digital preservation community might interact with the technology response model in various ways. The following technology responsiveness scenarios illustrate the kinds of interactions the digital preservation community might have, each of which would benefit from the accumulated current and historical content:

- A digital curator who manages a modest digital preservation programme and wants to develop a policy on preserving digital images searches the accumulated data for all relevant items regarding digital images and policies. The digital curator could also submit a request for a checklist of requirements for such a policy and a description of an action plan for implementing the policy that digital preservation technology responsiveness network contributors could then develop. The digital curator could request updates pertaining to standards for digital images, additional examples of policies identified, and news about new developments that would help maintain the resulting policy on preserving digital images. The digital curator could submit additional sources identified and the resulting policy as an example for other digital curators.

- A researcher who is interested in establishing a collaborative project to develop a migration methodology for the automated management of heterogeneous digital content could search the accumulated information for all relevant items on file formats, migration approaches, the development of preservation methodologies, similar or related migration research results, and the migration policies, procedures and practices. The researcher could use the information about relevant projects to identify potential collaborators and funding sources. The researcher could contribute updates on and results from the research project to the technology responsiveness network. Other participants in the technology responsiveness network could volunteer to be included in collaborative efforts and discussions. Researchers could volunteer to participate in technology assessments and register relevant expertise to be selected for technology reviews, technology assessments, or to contribute to the accumulation of content on particular topics, technologies, or domains.
- A professor for a graduate course on digital preservation could search accumulated information for relevant sources to help develop the course description, syllabus, reading lists, and assignments. The professor could generate bibliographies, select content for individual modules and lectures, and request additional information or whole modules, for either onsite or online delivery, to be developed by contributors to meet the instructor's needs. Educators and trainers could use the technology responsiveness network to support distance team teaching or distributed degree programmes. The technology responsiveness network could provide all or portions of course packs. Educators could contribute back to the technology responsiveness network the course description, syllabus, and lecture notes for relevant courses.

- A student taking a digital preservation course could search the accumulated information for items on digital audio files. The results include annotated citations to technical reports, updates, white papers and articles on the different types of digital audio files, relevant standards, latest developments in the industry, representative software applications, discussions of the preserving digital audio files, and Web sites for research projects and technology assessments that are looking at preservation implications for digital audio files. The student could generate a bibliography or a chronology for the results and save the search to request updates. The student could also submit additional sources for inclusion in the technology responsiveness network, possibly for credit. Content contributors would be identified with the entries and linked to profiles of contributors. Google Answers and similar services use a researcher registration process that is a model for this kind of registration to track the quality and allow users to determine the weight given to content.

To implement and sustain a technology response model for the digital preservation community, members would have to so value their participation in these and other scenarios for interacting with the implemented model that they will lend their continued support to it.

Technology responsiveness includes raising awareness about and developing *competencies* within the digital preservation community to develop and apply appropriate responses to technology developments. For this reason, competencies were explicitly included as a category in the technology framework. The digital preservation community will need to develop educational and training programs that build upon the content and services of the implementation of the technology response model. A digital curator may perform the role of educator, researcher, or practitioner. Each of these roles requires the acquisition of knowledge, skills, and abilities to accommodate new and emerging technologies. These roles require access to accumulations of accurate and approachable information about technology developments, both current and historical, to enable the informed development of curriculum, research methods, digital preservation strategies, policies and procedures, and repositories. An impact of ongoing technological change on communities that interact with and rely upon technology is the need to enable lifelong learning for its members to be always prepared.

In summary, there are a number of success factors to consider for the implementation of the technology response model. The activities required to implement the technology response model should be completed collaboratively, providing a starting point for building the community around the model. The technical infrastructure should be manageable and affordable to be sustainable. There should be defined roles and responsibilities to encourage and enable community participation and support. There should be measurable benefits to the community resulting from the implementation. For the technology response model implementation, community benefits would include timely awareness of relevant technology developments, increased understanding and familiarity with relevant technologies, and the availability of appropriate responses to technology as it emerges and evolves.

6.5 Further Research on Technology Responsiveness

This research produced the technology response model using results from the investigations of technological change and technology response. These results provide a comprehensive framework to define and enable technology responsiveness for digital preservation. Potential further research on technology responsiveness pertains to key areas for implementing the model for use within the digital preservation community.

Further research on the scope of interest in technology developments might define a protocol for extending and maintaining the technology framework and technology inventory for digital preservation; devise and test comprehensive discovery tools for applying the scope of interest to the accumulation of information about technology developments; and collaborate with the computer science and other communities to develop a view of the technology landscape that reflects the overlapping and specialised interests of communities in the range of information technology developments to enable sharing responsibility for technology responsiveness. A related area of research would be to apply, refine and adjust the priority criteria using specific examples of technology developments.

An area for further research would be to produce additional technology response examples that address other categories of the technology framework and other technologies on the inventory. Additional examples could involve identifying and evaluating frameworks for other categories of technology developments from the technology framework and the technologies inventory; instances that illustrate the means to discover and present information accumulated by the monitor stage for use in assessment; techniques for capturing and analysing results from each step of the assessment process; and techniques for extracting and analysing the results of technology assessments to support the development of digital preservation strategies and to contribute to the accumulation of available information about technology developments. Incorporating specific illustrations of the application of each technology response type into the technology response examples would help extend the understanding of the technology response model. Comparing and analysing the results produced by the examples would enable the capabilities and benefits of each technology response types to be more deeply integrated into the functionality and content components of the technology response model. This process would also contribute to the set of tools and techniques for technology responsiveness. This kind of research will require the application of archival skills, e.g., appraising digital content, developing and applying preservation strategies, and determining the implications of technology developments for preserving digital content, with active involvement by information and computer science experts.

Further research in the identification and characterisation of information sources about technology developments could produce a more exhaustive set of sources that addresses intellectual property and access issues for confidential and commercial sources of information, e.g., marketing reports. The results of such research could be used to automatically classify and annotate information accumulated through continual monitoring of technology developments for digital preservation. Weighting the information by source, value, and potential relevance would help the model generate alerts for the digital preservation community and complete technology assessments.

Another research area would involve testing the implementation of the content model for the technology response model by adapting the information packaging defined for OAIS. When information is initially received about a technology development, it could be treated as a SIP, ingested into the technology response implementation with a quality control process, managed as an AIP from that point on with the accumulation of metadata about the information as it is annotated and analysed being added to the stored objects, then distributed as a DIP on its own or in combination with other DIPs. The content of the technology response implementation would be retained for long periods and effectively preserved by the community for long-term use.

The extension of the research would involve the digital preservation community as users of the implementation of the model to provide feedback on proposed outputs and services. This would establish a partnership between research and development for enabling technology responsiveness within the digital preservation community. As new technologies require technology assessments or offer potential opportunities or challenges, the technology response implementation could be alerted to incorporate new technologies into the research agenda.

6.6 Recommendations

This section builds on the research and evaluation results to propose these recommendations for the digital preservation community regarding technology responsiveness:

- Convene a task force to consider the implementation of the technology response model for the community and restructure current approaches to make the most of the community's resources and interests;
- Establish a standing committee to refine the scope of interest in technology developments using the technology framework, technology inventory, and prioritisation process;

- Sponsor research to test and adapt technology responses that address the technology responsiveness research agenda to incorporate all four response types: awareness, exploitation, prevention, and adaptation;
- Address the human factor within the community by raising the awareness of members about technology developments through the services provided by the model, by training members through programs that utilise the content and services of the model, and by enabling members through the development of tools to respond to technology developments;
- Coordinate the accumulation and aggregation of information about technology developments by applying the expertise of members to address intellectual property issues and to develop approaches for storing and presenting different types of information for users of the model, for example; and
- Define a measurable plan that acknowledges the need first to monitor technology developments, then to assess them in response to cumulative technological change.

The early voices that recognised the challenge technology presented for preservation and the 1996 *Preserving Digital Information* report that specified the challenge paved the way for community action. The emergence of the digital preservation community and the capabilities of technology developments to allow the effective harvesting and analysis of massive amounts of information have combined to make a sustainable and comprehensive technology response program possible. The digital preservation community could determine that it is time to consolidate its accomplishments to date and establish a community-wide programme using the model to expand the scope and response. When asked about its response to technological change, it should be possible for the community to not only describe, but to also demonstrate its response.

6.7 Conclusion

Technology responsiveness enables the digital preservation community to be more aware of and prepared for relevant technology developments, so it can formulate informed and appropriate responses that incorporate the positive and avoid the negative implications of technological change. Appropriate responses might take the form of digital preservation strategies that address new types of digital content, digital preservation processes and techniques that integrate the capabilities of technology developments, or technology transfer projects that produce practical results or that increase the understanding of a technology development.

The technology response model formalises the functionality and content required for responding to technological change. As shown in its application to object-based systems, the model also considers the products and outcomes of the stages of the model. Implementation of the technology response model along with further research will draw on the best, most collaborative practices of the digital preservation community and provide results that support long-term preservation of digital content.

Annex 1. Detailed Results from the Scope of Interest Investigation

This annex contains four sections:

Section 1. Results of the Analysis of OAIS functions

Section 2. Types of Technologies Identified in OAIS Function Descriptions

Section 3. Identifying priorities for technology developments

Section 4. OAIS functions in order of Priority Score

Section 1. Results of the Analysis of OAIS functions

This section contains the results of analysing the descriptions of OAIS functions. These results are discussed in Sections 2.6 and 2.7 of the thesis.

Descriptions of columns in Table 1 below

ID: This column contains the identifier that was assigned for this analysis to provide a unique identifier for each OAIS function for explicit references.

OAIS Functional Group: This column identifies the OAIS functional group from the OAIS document to which the function belongs.

OAIS Function: This column lists the name of the function from the OAIS document and summarises the capabilities expected for the function. The text was synthesised from the OAIS document to make the results easier to review.

Role: This column was developed for the analysis to identify the type of role the function plays in digital preservation. The role of the function is important because maintaining the integrity of digital content throughout its lifecycle is essential for effective digital preservation. Direct contact with digital content in the digital preservation process immediately elevates those functions to a higher priority:

- *D* = a *direct* role indicates the function requires contact with digital content
- *E* = an *enabling* role indicates the function provides an important digital preservation function without having direct contact with digital content
- *I*= an *indirect* role indicates the function is less immediate to the preservation of the digital content

Technology / Functionality: This column identifies the technologies or functionality for the OAIS function as implicitly or explicitly (in *italics*) referred to in the description.

Table 1. Technologies referenced by OAIS function descriptions

ID	**OAIS Functional Entity**	**OAIS Function** (definition of intended capabilities)	**Role**	**Technology / Functionality**
1.1	Common Services	***Operating System services***: core services to operate and manage system, control access to data.	E	*software*, *mechanisms*, *access controls*, *services*, *utilities*, hardware interactions, logs
1.2	Common Services	***Network services***: enable distribution, interoperability, messaging – access, authentication, confidentiality, integrity	E	procedural protocols, hardware interactions, *security*, *access controls*, *authentication*, *integrity checking*, messaging mechanism, *services*, *confidentiality*
1.3	Common Services	***Security services***: support identification and authentication, access control, data integrity, data confidentiality	D	*services*, *security*, *access controls*, *authentication* , *integrity checking*, *confidentiality*
2.1	Ingest	***Receive Submission***: receive digital content (electronic or physical), access controls, confirmation receipt	D	*storage capability*, file formats, *storage media*, metadata, messaging mechanism, content transfer, *access controls*, *devices*
2.2	Ingest	***Quality Assurance***: validate digital transfer process and content	D	procedural protocols, *mechanisms*, file formats, storage media, *logs*, *checksum*, *utilities*, messaging mechanism
2.3	Ingest	***Generate AIP***: transforms SIP to AIP: e.g., file and data representation conversion, reorganises, requests and receives data reports and audit reports	D	procedural protocols, tools, *file formats*, *documentation standards*, *reporting*, *file conversion*, messaging mechanism, metadata, content transfer
2.4	Ingest	***Generate Descriptive Information***: extracts from AIPS and other sources information sent to coordinate updates to enable retrieval	E	*metadata*, messaging mechanism, tools

ID	OAIS Functional Entity	OAIS Function (definition of intended capabilities)	Role	Technology / Functionality
2.5	Ingest	***Coordinate Updates***: transfers AIPs to archival storage (electronic, physical, virtual), storage requests, storage identification, data management updates	D	metadata, procedural protocols, messaging mechanism, content transfer
3.1	Archival Storage	***Receive Data***: receives storage request criteria and AIP from ingest, performs transfer of AIPs to storage, sends receipt with identification	D	*storage media*, content transfer, messaging mechanism, *devices*, procedural protocols
3.2	Archival Storage	***Manage Storage Hierarchy***: issues commands reflecting storage policies to place AIPs, provide security and protection, monitors error logs, provides operational statistics	E	procedural protocols, storage media management, messaging mechanism, reporting, policy enforcement, *access controls*, *security*
3.2	Archival Storage	***Replace Media***: reproduce AIPs on media without change to content (refreshing, replicating, simple repackaging), confirm security and protection	D	procedural protocols, tools, *storage media*, messaging mechanism, file formats, metadata, access controls, integrity checking, security, content transfer
3.4	Archival Storage	***Error Checking***: statistical assurance of integrity during transfer, requires hardware and software error notification, tracking and verifying, random checking	E	procedural protocols, *mechanisms*, utilities, messaging mechanism, file formats, storage media, metadata, *services*, *logs*, reporting
3.5	Archival Storage	***Disaster Recovery***: duplicating and storing digital content in a separate location, specified by Administration	E	procedural protocols, *mechanisms*, *storage media*, file formats, metadata policy enforcement, content transfer
3.6	Archival Storage	***Provide Data***: provides copies of digital content to access; receives request, replies, and notifies	I	procedural protocols, mechanisms, *storage media*, messaging mechanism, file formats, metadata, content transfer
4.1	Data Management	***Administer Database***: contains descriptive and operational information, validates database integrity, complies with policies	E	data base development, procedural protocols, metadata, policy enforcement, integrity checking

ID	OAIS Functional Entity	OAIS Function (definition of intended capabilities)	Role	Technology / Functionality
4.2	Data Management	***Perform Queries***: receives requests from Access, generates response, delivers results	I	query languages and syntax, metadata, messaging mechanism
4.3	Data Management	***Generate Report***: receives report request from Ingest, Access, Administration; generates report, delivers results	I	query languages and syntax, metadata, reporting, messaging mechanism, procedural protocols
4.4	Data Management	***Receive Database Updates***: adds, modifies, deletes information in response to update requests from Ingest and Administration	I	metadata, messaging mechanism, reporting, procedural protocols
5.1	Administration	***Negotiate Submission Agreement***: defines submission agreement, deliverables from Producer, and schedule, tracks resources needed for ingest, receives AIP/SIP templates from Preservation Planning, sends SIP designs and SIPs to Audit Submission, reflects data submission policies	E	procedural protocols, tracking, reporting, natural language processing, messaging mechanism, policy enforcement
5.2	Administration	***Manage System Configuration***: systems engineering, continual monitoring of archive; change management – change requests, procedures, tools; maintains system integrity; sends requests; receives reports; sends performance updates	E	*system engineering*, requirements analysis, procedural protocols, reporting, query languages/syntax, system maintenance, messaging mechanism, *tools*, *audit controls*, integrity checking, *monitor*, artificial intelligence
5.3	Administration	***Archival Information Update***: updating digital content, sends requests to Access to generate DIPs to resubmit as SIPs to Ingest	E	procedural protocols, messaging mechanism, *tools*
5.4	Administration	***Physical Access Control***: restricts or allows physical access in compliance with policies	E	procedural protocols, *mechanisms*, policy enforcement

ID	OAIS Functional Entity	**OAIS Function** (definition of intended capabilities)	Role	Technology / Functionality
5.5	Administration	***Establish Standards and Policies***: establish and maintain standards and policies, receives budget and policies from Management, provides reports to Management, receives recommendations and proposals from Preservation Planning, sends policies (storage management, disaster planning, disaster recovery), standards (format, documentation), migration goals	E	procedural protocols, natural language processing, reporting, messaging mechanism, policy enforcement, artificial intelligence
5.6	Administration	***Audit Submission***: verifies SIPs or AIPs meet data quality and other requirements, provides audit report, provides final ingest report	D	procedural protocols, reporting, audit controls, messaging mechanism, policy enforcement, human computer interface, natural language processing, artificial intelligence
5.7	Administration	***Activate Requests***: maintains record of event-driven requests (e.g., database update), periodically generates requests to Access, can generate Consumer orders on event occurrence	I	query languages/syntax, tracking, messaging mechanism
5.8	Administration	***Customer Service***: manages customer accounts including bills and payments, respond to general information requests, collect and respond to feedback	I	procedural protocols, tracking, e-commerce, messaging mechanism, natural language processing, reporting
6.1	Preservation Planning	***Monitor Designated Community***: monitors community; tracks changes in requirements, technologies, preferences (formats, media, software); surveys; provides reports, alerts, requirements	E	*tracking*, requirements analysis, reporting, messaging mechanism, human computer interface, monitor
6.2	Preservation Planning	***Monitor Technology***: tracks emerging technologies, standards for potential obsolescence; may support prototyping and receive prototyping requests; sends reports, prototype results, standards, alerts	E	*tracking*, reporting, *prototyping*, messaging mechanism, monitor

ID	OAIS Functional Entity	OAIS Function (definition of intended capabilities)	Role	Technology / Functionality
6.3	Preservation Planning	***Develop Preservation Strategies and Standards***: develops and recommends strategies and standards, monitors need for migration, receives reports, sends recommendations, receives standards and provides profiles of standards, receives issues and responds with advice	E	requirements analysis, artificial intelligence, natural language processing, tracking, procedural protocols, reporting, messaging mechanism, human computer interface
6.4	Preservation Planning	***Develop Packaging Designs and Migration Plans***: develops information package designs, migration plans (test, review, and implementation plans), prototypes; provides advice on applying and reviewing; receives approved standards and migration goals and provides AIP / SIP templates; sends issues and receives advice	E	requirements analysis, *prototyping*, artificial intelligence, natural language processing, procedural protocols, reporting, metadata, documentation standards, messaging mechanism, human computer interface
7.1	Access	***Coordinate Access Activities***: provides a single interface for users, sends and receives results for query, report, and dissemination requests (ad hoc and event-based), supports users	I	procedural protocols, reporting, tracking, messaging mechanism, access controls
7.2	Access	***Generate DIP***: receives dissemination requests, retrieves AIP and descriptive information, moves a copy for processing, applies special processing, notifies when ready	I	procedural protocols, reporting, messaging mechanism, content transfer
7.3	Access	***Deliver Response***: manages online and offline deliveries, receives reconfirmation, prepares for transfer, notifies	I	procedural protocols, reporting, tracking, messaging mechanism, content transfer

Section 2. Types of Technologies in OAIS Function Descriptions

This section provides a brief explanation of the technologies and technological functionalities that were identified in Section 1 that were developed for the research. These results are summarised in Section 2.6 of Chapter 2.

Table 2. Technological functionality identified in OAIS functions.

Technology / Functionality	**Explanation**
access controls	A specialised mechanism to provide or prevent access to digital content at the repository, collection, or object level
artificial intelligence	Describes the automated means to perform specific activities using defined rules. Policies must be deconstructed into rules that can then be applied to activities within an OAIS
audit controls	The means to provide audit control for a system, often using a log that documents the time and person performing each action that occurs in a system
authentication	The ability to confirm the identity of a user against a list of authorised users.
checksum	A utility that calculates a unique value for each digital file. It is a means for detecting changes in digital files.
confidentiality	The ability to manage and control the confidentiality of the users or content.
content transfer	A controlled, secure, and documented process for moving digital content from one storage location to another.
database development	The structured definition and implementation of a purpose-built digital container for a specific set of information. A digital repository may rely upon one or more databases to organise and manage its content.
devices	A self-contained mechanism that may involve peripheral equipment and performs a specific function. Storage management often use devices.
documentation standards	A specification of the requirements for documentation of digital content as adopted or established by the archive.
e-commerce	Technology that enables the monetary exchange of goods or information.
file formats	Specifications for storing the bits of a digital file. File format specification are often standardised.
hardware interactions	IT protocols that dictate the settings and instructions for interactions between the hardware within or between information systems.
human computer interface	The structured presentation of information to users of a system to provide a service or perform a function. Users in an OAIS could be represented by any one of the roles.
integrity checking	The ability to ensure the content of a digital object has not been altered internationally or unintentionally. Checksums is a common means used for integrity checking.
logs	A computer log contains information about activities performed by or for an information system. These are usually stored in standard formats.

mechanisms	A tool that enables the performance of an activity by an information system possibly with mechanical assistance, e.g. an implement for recording digital signatures.
messaging mechanism	The ability to convey a message or a specific piece of information between two functions.
metadata	Structured information about repositories, collections, objects, functions, tools, and other entities used by an OAIS. Specialised and standardised sets of technical, administrative, and descriptive metadata play an important role in digital preservation.
monitor	The ability to look for and detect changes and occurrences to inform or enable a response.
natural language processing	The ability for a computer to operate using human language constructs.
policy enforcement	The ability for an information system to perform functions using rules to allow or prohibit activities.
procedural protocols	A set of steps or instructions that define an activity according to a specific sequence, structure, or set of rules.
prototyping	The development of a system, program, or tool that demonstrates functionality and may then be converted or translated for production use.
query languages and syntax	There are common often standardised formats for queries, such as SQL. A repository, database, or program must be able to generate and receive queries using common query formats.
reporting	The ability to compile, format, and convey Reporting could use specialised tools or utilities depending on the complexity of the reporting requirements.
requirements analysis	The ability to parse and construct requirements from formal requirements documents and to evaluate the implementation of requirements based on performance measures for an information system.
security	The ability to protect a repository, collection, or object by allowing or prohibiting actions based on a defined set of rules. Security encompasses policy enforcement, procedural protocols, authentication and other functionality in support of a security policy.
services	The ability to perform a generalised function, e.g. get a file, copy an object. Increasingly within the context of digital repositories, services refer to web services and services are generalised for use between repositories.
software	A higher-level computer program developed to consistently and reliably perform a specific function or set of functions. Software may rely upon tools, utilities, mechanisms and other lower-level technological components, but the program includes the rules and instructions for using lower-level components.
storage capacity	The ability to calculate the requisite storage needs for a digital repository, digital collections, or digital objects.

storage media	A device for storing digital content. As new types of storage media emerge, standardised specifications are defined to allow for production level use. Some storage media that are of higher quality and greater durability are described as archival storage media. The media with designation change over time as technology evolves.
storage media management	The ability to monitor and manage an array of online, nearline, and offline storage media to meet the needs of a repository.
system engineering	A domain of computer science that is dedicated to exploring and devising the means to build systems in accordance with evolving requirements and that utilise technology developments.
system maintenance	The ability to monitor information systems to detect, report, or fix potential problems.
tools	An individual or combination of specialised and purpose-built computer programs, tools, or utilities devised to complete a sequence of activities in support of a function.
tracking	The ability to monitor and record activities or events within an information system.
utilities	A common or generalised program or tool that supports a function, e.g. a reporting utility.

Section 3. Identifying priorities for technology developments

This section contains the results of using the priority criteria to evaluate the priority of technology developments based on OAIS function. These results are discussed in Section 2.7 of Chapter 2.

Descriptions of the columns in Table 3

Column

ID: This identifier provides a unique identifier for each OAIS function.

OAIS Functional Group: The OAIS functional group to which the function belongs.

OAIS Function: This column names the function and summarises the capability envisioned for the function as distilled from the OAIS reference model.

Columns 1-5 in the table correspond to the five Priority Criteria. The priority criteria are discussed in Section 2.7 of Chapter 2.

Column Number	*Priority Criteria*
1	contact
2	interaction
3	opportunity
4	threats
5	automation

10 points indicates the priority criterion definition fully applied to the OAIS function
5 points indicates the priority criterion definition partly applied to the OAIS function
0 points indicates the priority criterion definition did not apply to the OAIS function

Score: Presents the total priority score for each OAIS function.

Table 3. Priority scores for OAIS functions using priority criteria.

ID	Functional Group	OAIS Function	1	2	3	4	5	Score
1.1	Common Services	Operating System services	5	5	5	5	10	30
1.2	Common Services	Network services	5	5	5	10	10	35
1.3	Common Services	Security services	10	10	10	10	10	50
2.1	Ingest	Receive Submission	10	10	10	10	10	50
2.2	Ingest	Quality Assurance	10	10	10	10	10	50
2.3	Ingest	Generate AIP	10	10	10	10	10	50
2.4	Ingest	Generate Descriptive Information	5	5	5	5	10	30
2.5	Ingest	Coordinate Updates	10	10	10	10	10	50
3.1	Archival Storage	Receive Data	10	10	10	10	10	50
3.2	Archival Storage	Manage Storage Hierarchy	5	5	10	10	5	35
3.2	Archival Storage	Replace Media	10	5	10	10	10	45
3.4	Archival Storage	Error Checking	10	5	10	10	10	45
3.5	Archival Storage	Disaster Recovery	10	5	10	10	10	45
3.6	Archival Storage	Provide Data	10	5	0	0	5	20
4.1	Data Management	Administer Database	0	5	5	10	10	30
4.2	Data Management	Perform Queries	0	0	0	0	5	5
4.3	Data Management	Generate Report	0	5	0	0	5	10
4.4	Data Management	Receive Database Updates	0	5	5	5	5	20
5.1	Administration	Negotiate Submission Agreement	0	5	10	10	10	35
5.2	Administration	Manage System Configuration	0	5	10	10	10	35
5.3	Administration	Archival Information Update	0	10	10	5	10	35
5.4	Administration	Physical Access Control	5	0	5	5	5	20
5.5	Administration	Establish Standards and Policies	0	10	10	10	10	40
5.6	Administration	Audit Submission	10	10	10	10	10	50
5.7	Administration	Activate Requests	0	5	0	0	5	10
5.8	Administration	Customer Service	0	0	0	0	0	0
6.1	Preservation Planning	Monitor Designated Community	0	10	10	10	5	35
6.2	Preservation Planning	Monitor Technology	0	10	10	10	10	40
6.3	Preservation Planning	Develop Preservation Strategies and Standards	0	10	10	10	10	40
6.4	Preservation Planning	Develop Packaging Designs and Migration Plans	0	10	10	10	10	40
7.1	Access	Coordinate Access Activities	0	5	5	0	5	15
7.2	Access	Generate DIP	5	5	10	5	10	35
7.3	Access	Deliver Response	0	0	5	0	5	10

Section 4. OAIS functions in order of Priority Score

This section summarises the results from Table 3 and presents the results in reverse order from highest to lowest priority score. These results are discussed in Section 2.7 of Chapter 2.

Table 4. OAIS functional entities and functions by priority score.

Score	OAIS Functional Group: OAIS Function
50	*Administration*: Audit Submission
	Archival Storage: Receive Data
	Common Services: Security services
	Ingest: Coordinate Updates
	Ingest: Generate AIP
	Ingest: Quality Assurance
	Ingest: Receive Submission
45	*Archival Storage*: Replace Media
	Archival Storage: Error Checking
	Archival Storage: Disaster Recovery
40	*Administration*: Establish Standards and Policies
	Preservation Planning: Monitor Technology
	Preservation Planning: Develop Preservation Strategies and Standards
	Preservation Planning: Develop Packaging Designs and Migration Plans
35	*Access*: Generate DIP
	Administration: Archival Information Update
	Administration: Manage System Configuration
	Administration: Negotiate Submission Agreement
	Archival Storage: Manage Storage Hierarchy
	Common Services: Network services
	Preservation Planning: Monitor Designated Community
30	*Common Services*: Operating System services
	Data Management: Administer Database
	Ingest: Generate Descriptive Information:
20	*Administration*: Physical Access Control
	Archival Storage: Provide Data
	Data Management: Receive Database Updates
15	*Access*: Coordinate Access Activities
10	*Access*: Deliver Response
	Administration: Activate Requests
	Data Management: Generate Report
5	*Data Management*: Perform Queries
0	*Administration*: Customer Service

Annex 2: Profiles for Technology Watch Survey

This is the list of technology watch examples that were implemented within the digital preservation community or by other communities that were surveyed for this research. These profiles support the discussion of technology watch examples in Chapter 3 of this thesis. Searching for this list began in 1999. The Web sites that host these technology watch examples were last checked on 25 May 2008. Changes in the status or content of these examples that may have occurred after that date are not reflected in these profiles.

Categories of examples

1. **Digital Preservation Examples**
2. **National and International Technology Watch Initiatives**
3. **Other domains: Technology Analysts**
4. **Other domains: Industry-specific**

1. Digital Preservation Examples

1a. *Name*: **PRONOM**

Brief description: This is an online registry of information about software packages and the file formats the software supports. PRONOM provides historical information about versions of the software and the file formats.

Start-End dates: 2002-

Focus: Technical information about software packages and file formats over time

Services: Online searching, continual monitoring for software and file format updates

Products: searchable database of information, tools

Sponsorship/funding: Digital Preservation Department, The National Archives

URL: http://www.nationalarchives.gov.uk/pronom/

Comments: PRONOM was named when The National Archives was still the Public Records Office (PRO). PRONOM addresses key digital preservation issues: current and historical information about file formats and related software.

1b. *Name*: **Digital Preservation Coalition - Reports**

Brief description: The DPC has been sponsoring Technology Watch Reports. These are grouped on their Web site with links to major external digital preservation reports, UK needs assessment reports, and DPC annual reports. Since 2002, the DPC has also produced quarterly summaries of digital preservation in cooperation with Preserving Access to Digital Information (PADI).

Start-End dates: -

Focus: Digital preservation-related topics

Services: Monitoring for digital preservation updates, training, working meetings

Products: Reports, quarterly news

Sponsorship/funding: Membership fees

URL: http://www.dpconline.org/graphics/reports/

Comments: The DPC produced four technology watch reports between Jan 2004 and September 2005. Each report focuses on a single topic: preservation metadata, large-scale archival storage, institutional repositories, and an introductory guide to the Open Archival Information System (OAIS) Reference Model. The DPC provides both members-only and public information.

1c. *Name*: **Preserving Access to Digital Information (PADI)**

Brief description: PADI maintains current and historical links to international developments in the digital preservation community. Topics include: "What's new in digital preservation", Data Documentation & Standards, Digital Libraries, Digital Records, Digitisation, Formats & Media, Management, National Approaches, Rights Management, Strategies, and Web Archiving. Sources include: events, policies, strategies, guidelines, projects, Web sites, bibliographies, discussion lists, glossaries, journals, newsletters, and news. PADI goes beyond linking by ensuring long-term access to the links either directly or by coordinating with the source institutions. Topics begin with an introduction followed by annotated citations with links to resources. The citations identify *Safekept* resources that are being preserved; and *historical* resources that are more than five years old and are not being preserved.

Start-End dates: 1996-

Focus: Organisational and technology developments pertaining to digital information

Services: Ongoing monitoring, updates, support for submitting contributions

Products: Topics with annotated citations and links, quarterly summaries (with DPC)

Sponsorship/funding: National Library of Australia with sponsorship from the Council on Library and Information Resources (CLIR) and in cooperation with the Digital Preservation Coalition of the UK.

URL: http://www.nla.gov.au/padi/

Comments: This is perhaps the longest running and most successful technology watch example for digital preservation.

1d. *Name*: **DigiCult Technology Watch reports**

Brief description: The technology watch component of DigiCult included annual reports covering six selected technologies the authors predicted would have a significant impact for cultural heritage institutions, professionals, and collections. The DigiCult technology watch program also included technology watch briefings, which were drafts made available prior to the completion of the final version of the annual reports. Related DigiCult services included thematic and special issues reports that provided a more detailed look at a single topic; periodic newsletters with updates on a range of digital culture topics; resources grouped by theme; an events listing; and a cv and job service.

Start-End dates: 2002-2005

Focus: Technology developments with potential impact on cultural heritage

Services: Monitoring of technology developments in targeted areas

Products: Annual technology reports, pre-print drafts

Sponsorship/funding:

URL:http://www.digicult.info/pages/techwatch.php?PHPSESSID=7a21b16818d244bc6864aa539544d753

Comments: DigiCult produced three reports between 2003 and 2004 when the program ended. DigiCult was funded by a grant from the European Union. The subtitle for the program was: "Technology challenges for digital culture."

1e. *Name*: **Electronic Resource Preservation and Access NETwork (erpanet)**

Brief description: The erpaAssessment service provided abstracts of articles, monographs, and projects pertaining to digital preservation topics. In addition, erpaDirectory provided an A-Z listing of abstracts for resources erpanet was tracking and erpaEprints provided full-text access to approximately 50 publications from 1995 to 2004. ErpaAdvisory was a question and answer service. Users could post questions and a digital preservation specialist in the ErpaNet network would respond. Twenty-one questions were responded to between 2002 and 2004; three unanswered questions remained in July 2005. ErpaEvents provided a calendar of seminars, workshops, and working meetings on digital preservation. ErpaGuidance produced five documents providing background and recommendations on digital preservation topics. ErpaStudies provided digital preservation case studies on institutional programs. ErpaDocumentation provided links to seminar reports, workshop reports, and staff presentations. Erpanet also drafted a set of principles to guide digital preservation efforts.

Start-End dates: 2002-2004

Focus: technological and community developments pertaining to digital preservation

Services: Information sharing, advisory services, training

Products: Reports, annotated directories, guidance, course materials

Sponsorship/funding: European Commission under the IST programme plus support from institutions in the UK, the Netherlands, Italy, Switzerland and a partnership with PADI.

URL: http://www.erpanet.org/

Comments: Erpanet sought to be a comprehensive service for the digital preservation community. One goal of erpanet was to use the grant funding to establish a sustainable program. Recent funding from the European Union may enable the continuation of erpanet's efforts in a revised format.

1f. *Name*: **Berkeley Digital Library SunSITE**

Brief description: The Preservation Information section of the Berkeley SunSITE includes these categories of links to web sites: Articles & Papers, Current Awareness, Initiatives & Projects, Organisations, Policy Examples, Resources, and Tools.

Start-End dates: mid-1990s

Focus: Developments pertaining to preservation, including digital

Services: Monitored events and developments in the preservation community

Products: Directory of links to online information

Sponsorship/funding:

URL: http://sunsite.berkeley.edu/

Comments: This is included as an early example of monitoring and information sharing that responded quickly to the advent of the World Wide Web to serve the preservation community. Most of the links are outdated, except those to other information services, e.g., PADI.

1g. *Name*: **Library and Information Technology Association (LITA) Technology Trends**

Brief description: At the annual and midwinter meetings of the American Library Association (ALA), LITA presents its list top ten technology trends. The lists of trends are available on the LITA Web site by meeting and by topic. The Web site identifies the experts who spot trends for LITA as well as additional readings that have been recommended by these experts. LITA also provides a toolkit for expert web searchers

Start-End dates: 1999-

Focus: Technology trends of interest to libraries

Services: Monitoring for trends, access to experts

Products: Lists of trends, associated reading, web search toolkit

Sponsorship/funding: LITA, a division of ALA

URL: http://www.lita.org/committe/toptech/mainpage.htm

Comments: The technologies trends are not specific to digital preservation, but the results are of interest beyond the library community and the approach makes it an interesting example.

2. National and International Technology Watch Initiatives

2a. *Name*: **Cyberinfrastructure Technology Watch**

Brief description: This service is intended to provide a forum to discuss the latest technological innovations and developments relating to the cyberinfrastructure for science.

Start-End dates: Feb 17, 2005-

Focus: Cyberinfrastructure for science

Services: Community forum

Products: blog (*CTWatch Blog*), online journal (*CTWatchQuarterly*)

Sponsorship/funding: CyberInfrastructure Partnership (CIP), a joint effort led by the National Center for Supercomputing Applications (NCSA) and the San Diego Supercomputer Center (SDSC)

URL: http://www.ctwatch.org/

Comments: In 2003, the National NSF launched their cyberinfrastructure program with the release of their report *Revolutionizing Science and Engineering Through Cyberinfrastructure* to address concerns about conducting science over time in a digital environment. The NSF intends the term cyberinfrastructure to encompass all aspects of the technological environment, e.g., equipment, people, policies, software, networks, physical, and virtual, that are engaged in research, education, and practice pertaining to science. That definition defines a broad scope for this initiative. This example represents a high-profile, national initiative with strong international connections that provides structure and support for a technology watch initiative for information technology. Its primary purpose is communication, information sharing, and collaboration.

2b. *Name*: **Technology and Standards Watch**

Brief description: The charge to this technology watch service is to identify and track developments of information and communications technology and standards with relevance for higher and further education (HE/FE), commission work from experts, ensure awareness within JISC of effective use of identified technologies and standards, disseminate information to inform the community.

Start-End dates: 2000-

Focus: Developments in information and communications technology for HE/FE

Services: Monitoring of developments, information dissemination, recommendations, training

Products: Commissioned reports, alerts, A-Z of technologies, links to standards initiatives, report template

Sponsorship/funding: The Joint Information Systems Committee (JISC), UK

URL: http://www.jisc.ac.uk/index.cfm?name=techwatch_home

Comments: This is the only publicly-available template for a technology watch report that was discovered in this review.

2c. *Name*: **Technology Watch and Evaluation**

Brief description: This initiative integrates Technology Watch and Technology Evaluation.

Start-End dates: undated.

Focus: Text mining, research evaluation, technology transfer, topical technological citations (gas dynamics, thermal stresses, fusion, economics and finance)

Services: Information dissemination

Products: Publications, presentations, news and updates, annotated directory of links to recommended web sites including newsworthy events

Sponsorship/funding: U.S. Office of Naval Research

URL: http://www.onr.navy.mil/sci_tech/33/332/archived_11292007/techno_watch_presentations.asp

Comments: The content dates from the early 1980s into the 2000s. Individual web pages were updated as recently as December 2005. There is an emphasis on the text mining component with numerous references to literature-based discovery.

2d. *Name*: **Technology Watch: General Correspondence Group**

Brief description: The general correspondence group provides a public forum on the technology watch to enable and encourage the discussion of emerging information and communications technology.

Start-End dates: 2004-

Focus: Information and communications technology developments

Services: Information sharing

Products: Updates, standards work based on needs identified by the technology watch

Sponsorship/funding: International Telecommunication Union (ITU-T)

URL: http://www.itu.int/ITU-T/techwatch/general.asp

Comments: This initiative is related to the Joint Technical Committee on information technology standardisation (JTC 1) Special Working Group on Technology Watch.

2e. *Name*: **Technology Watch Center**

Brief description: This national service was established to acquire and disseminate information on available technologies and to provide forecasts on the potential impact of technologies on targeted research and development areas.

Start-End dates: 2001-

Focus: Aquaculture, food science, rubber and polymers, textiles, environmental science, manufacturing, biotechnology, electronics, and information technology

Services: information sharing, technology forecasts

Products: Newsletters, online databases for industry contacts and offers and training

Sponsorship/funding: National Science Foundation of Sri Lanka

URL: http://www.nsf.ac.lk/adbmost/twc/twc.htm

Comments: The most recent newsletter on the Web site is dated April 2005. It is possible that this initiative is ending or fading; it is also possible that there is a delay in making the content public. Their technology watch scope is broader than information technology.

2f. *Name*: **Technology Information, Forecasting & Assessment Council (TIFAC)**

Brief description: This is a government initiative for a large country

Start-End dates: early 1990s

Focus: Appropriate technology for India for information technology as well as agricultural and manufacturing

Services: Ongoing monitoring of global technology trends, technology assessment, recommendations on technology use and options, patent facilitation

Products: Technology forecasts, technology assessments, reports, technology source information, information sharing, patent database

Sponsorship/funding: Autonomous agency under the Department of Science and technology in India

URL: http://www.tifac.org.in/

Comments: TIFAC is one example that explicitly refers to technology assessment, transfer, and forecasting within its technology watch service in the description of its approach.

2g. *Name*: **Technology Watch**

Brief description: 'Geospatial Info-Mobility Service by Real-Time Data-Integration and Generalisation (GiMoDig). This technology watch was provided by a grant-funded project entitled: GiMoDig, a shortened form of Geospatial info-mobility service by real-time data-integration and generalisation. The goal of the project was to develop methods for delivering geospatial data to a mobile user.

Start-End dates: March 2003 – December 2004

Focus: Technology developments and updates for the GIS community

Services: Monitoring of GIS-related developments

Products: Monthly updates with links to longer stories

Sponsorship/funding: European Union via the Information Society Technologies (IST) programme. The project included participation by governement agencies in Finland, Denmark, Sweden

URL: http://gimodig.fgi.fi/watch.php

Comments: This three-year project was established in 2001. This is a good example of a technology watch for a specific topic or technology.

3. Other domains: Technology Analysts

3a. *Name*: **Gartner**

Brief description: Gartner is a large international research consulting group with a long track record for surveying technology and its potential implications for business. They offer university subscriptions to their technology research results.

Start-End dates: 1979-

Focus: business and technology, information technology investments

Services: Research, forecasting, industry advisory services, consulting, training

Products: Books, reports, articles, citations, customised analyses

Sponsorship/funding: Subscriptions and fees

URL: http://www.gartner.com/

Comments: The start date reflects when the company was established. They offer users various perspectives on their results using a range of visual displays is emphasised. To present current information about vendors and products they offer Magic Quadrants and Marketscopes that rate current use of technology and evaluate the potential impact of technologies. In presenting forecasting information, they offer hype cycles that evaluate the potential of recent and promised technology developments.

3b. *Name*: **Outsell**

Brief description: Outsell is a research consulting firm that provides market analyses for the information industry. Outsell works with publishers, commercial information providers, and software vendors. They also work with corporate, government, and academic sectors on benchmarking and best practices.

Start-End dates: 1994-

Focus: information content industry

Services: research, advisory service, monitoring of information industry, training

Products: Market analyses, reports, advice

Sponsorship/funding: Consulting fees, membership

URL: http://www.outsellinc.com/

Comments: The start date reflects when the company was established. Outsell offers levels of services. For information technology professional they offer InfoAboutInfo with levels from awareness, to action, to continuous learning.

3c. *Name*: **Aberdeen's Technology Forecasting Consortium**

Brief description: An international consulting firm that caters to the Global 5000. They provide research services for businesses and industries. The research topics of their technology watch products and services include retail, supply, finance human resources as well as information technology investment and other information technology-related issues.

Start-End dates: 1996-

Focus: Market analysis, business and technology

Services: Research, consulting, benchmarking

Products: Reports, articles

Sponsorship/funding: Membership, consulting services and fees

URL: http://www.aberdeen.com/default.asp

Comments: This service refers to their community research agenda and the ways in which their research products reflect research requests from clients.

3d. *Name*: The **MASIE Center**

Brief description: The MASIE Center is an international consulting service on learning in the digital environment that provides services to corporations and technology vendors.

Start-End dates: 1986-

Focus: Learning and technology, digital collaboration

Services: Research, advisory services, training

Products: Research reports, articles and citations, e-books, learning strategies, usability audits

Sponsorship/funding: Consulting and other fees

URL: http://www.masieweb.com/external/learning-trends.html

Comments: The start date reflects when the company was established. This service was founded by Elliott Masie. The Web site describes Masie as a futurist and the service as an e-lab and think tank and This is one of the few examples that focuses on learning in relation to technology and on usability.

3e. *Name*: **Cutter Consortium**

Brief description: The Cutter Consortium is an international consulting service. Its research topics include software development, information technology strategies for organisations, technology trends and impacts, and risk management.

Start-End dates: 1986-

Focus: Business and technology

Services: Research, advisory services, training,

Products: Journals, research reports, executive reports and updates, email advisories, training tools

Sponsorship/funding: Consulting and other fees

URL: http://www.cutter.com/consortium/advisory_trends.html

Comments: The start date reflects when the company was established; Online resources begin in the mid-1990s. This service focuses heavily on the role of information technology in organisations and organisational change in response to evolving technology.

3f. *Name*: **Executive Perspectives: Technology Watch**

Brief description: This technology watch is a component of an online publication *Executive Perspectives*. QinetiQ is a UK-based defence and security company.

Start-End dates: undated.

Focus: Technology trends for business executives

Services: Technology news and updates

Products: Abstracts on technology updates, technology reports, case studies, white papers

Sponsorship/funding: Consulting fees

URL: http://www.qinetiq.com/home_timpa/news/ti_tech_watch.html

Comments: The technology watch updates are dated October 2004 to November 2005. Reports are dated November 2003 to December 2005. The Web site states that QinetiQ is a privatised national defence laboratory to transition to the private sector with access to 50 years of output.QinetiQ provides technology watch updates aimed at business executives. The technology watch is generated by the research it conducts for its consulting business.

4. Other domains: Industry-specific (not information-based technologies)

4a. *Name*: **CIB-BBRI Technology Watch**

Brief description: The purpose of this technology watch is to seek out technologies that can be adapted for construction purposes, identify gaps, and look for new development areas. It was initiated as a project to present its findings at an international conference in 2001 and develop next steps.

Start-End dates: 1999-2001

Focus: Construction industry

Services: Searches for potential technologies in other sectors

Products: Case studies

Sponsorship/funding: Belgian Building Research Institute (BBRI) for the International Council for Research and Innovation in Building and Construction (CIB)

URL: http://www.bbri.be/technologywatch/pages/site_index.html

Comments: Construction is one of a number of materials-related technology watch examples. They use classic technology watch language – adapt, adopt, develop – in describing their purpose.

4b. *Name*: **EPRI Techhnology Innovation**

Brief description: The Electric Power Research Institute (EPRI) is a non-profit scientific research center for public interest energy and environmental research that was established in 1973. The technology watch component targets scientific developments, innovations, and associated cost implications for the energy industry. The online content covers 2005-2006.

Start-End dates: 1973-

Focus: Energy industry, developments that affect renewable energy

Services: Market analysis, regulation tracking, technology tracking

Products: Updates (various formats), advisories

Sponsorship/funding: membership service, additional fees

URL: http://portfolio.epri.com/2008_TechInn.aspx

Comments: The start date reflects the establishment of the research center. This technology watch is a good example of a membership-based service. EPRI shows up in technology watch searches and provides technology watch services, but does not label the Web site as a technology watch. URL updated in 2008.

4c. *Name*: **Key Findings**

Brief description: This is a technology tracking consulting service for businesses with special services for the advertising and healthcare industries. There have a special focus on generations in the workplace.

Start-End dates: 1997-2003

Focus: Business, marketing, advertising, healthcare

Services: Research, customised market analyses

Products: special reports, newsletters, FAQ, glossaries

Sponsorship/funding: fee-based consulting service

URL: http://www.keyfindings.com/technology/

Comments: The language and approach of this example seems to be fairly common for commercial technology watch providers. Key Findings may be operating under a different name now, but there was no identifiable connection to a current service.

4d. *Name*: **PATHnet**

Brief description: This technology watch was established to encourage the development and use of technologies for better housing by identifying and removing barriers, providing information, encourage research and development.

Start-End dates: 2003-

Focus: Housing industry

Services: Alerts, updates, research

Products: Research reports, technical practice reports, articles

Sponsorship/funding: This technology watch is affiliated with the U.S. Department of Housing and Urban Development (HUD). The Office of Policy Development and Research manages the budget. It is a voluntary partnership.

URL: http://www.pathnet.org/sp.asp?mc=about_topics

Comments: This technology watch is a good example of the public sector stepping in to provide current technology-related information through a technology watch service to a targeted industry.

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