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**DRAFT NIST Big Data Interoperability Framework: Volume 9, Adoption and Modernization**

NIST Big Data Public Working Group

Standards Roadmap Subgroup

Draft Version 2

August 7, 2017

https://bigdatawg.nist.gov/V2\_output\_docs.php



NIST Special Publication 1500-10

Information Technology Laboratory

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National Institute of Standards and Technology

Gaithersburg, MD 20899

This draft publication is available free of charge from:

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August 2017



U. S. Department of Commerce

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National Institute of Standards and Technology

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*and Acting NIST Director*

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**Comments on this publication may be submitted to Wo Chang**

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Request for Contributions

The NIST Big Data Public Working Group (NBD-PWG) requests contributions to this draft Version 2 of the *NIST Big Data Interoperability Framework (NBDIF): Volume 9, Adoption and Modernization.* All contributions are welcome, especially comments or additional content for the current draft.

The NBD-PWG is actively working to complete Version 2 of the set of NBDIFdocuments. The goals of Version 2 are to enhance the Version 1 content, define general interfaces between the NIST Big Data Reference Architecture (NBDRA) components by aggregating low-level interactions into high-level general interfaces, and demonstrate how the NBDRA can be used.

To contribute to this document, please follow the steps below as soon as possible but no later than September 21, 2017.

1. Obtain your user ID by registering as a user of the NBD-PWG Portal (https://bigdatawg.nist.gov/newuser.php)
2. Record comments and/or additional content in one of the following methods:
   1. **TRACK CHANGES**: make edits to and comments on the text directly into this Word document using track changes
   2. **COMMENT TEMPLATE**: capture specific edits using the Comment Template (<http://bigdatawg.nist.gov/_uploadfiles/SP1500-1-to-7_comment_template.docx>), which includes space for section number, page number, comment, and text edits
3. Submit the edited file from either method above by uploading the document to the NBD-PWG portal (https://bigdatawg.nist.gov/upload.php). Use the User ID (obtained in step 1) to upload documents. Alternatively, the edited file (from step 2) can be emailed to SP1500comments@nist.gov with the volume number in the subject line (e.g., Edits for Volume 1).
4. Attend the weekly virtual meetings on Tuesdays for possible presentation and discussion of your submission. Virtual meeting logistics can be found at https://bigdatawg.nist.gov/program.php

Please be as specific as possible in any comments or edits to the text. Specific edits include, but are not limited to, changes in the current text, additional text further explaining a topic or explaining a new topic, additional references, or comments about the text, topics, or document organization.

The comments and additional content will be reviewed by the subgroup co-chair responsible for the volume in question. Comments and additional content may be presented and discussed by the NBD-PWG during the weekly virtual meetings on Tuesday.

Three versions are planned for the NBDIF set of documents, with Versions 2 and 3 building on the first. Further explanation of the three planned versions, and the information contained therein, is included in Section 1 of each NBDIF document.

Please contact Wo Chang ([wchang@nist.gov](mailto:wchang@nist.gov))with any questions about the feedback submission process.

Big Data professionals are always welcome to join the NBD-PWG to help craft the work contained in the volumes of the NBDIF. Additional information about the NBD-PWG can be found at <http://bigdatawg.nist.gov>. Information about the weekly virtual meetings on Tuesday can be found at https://bigdatawg.nist.gov/program.php

Reports on Computer Systems Technology

The Information Technology Laboratory (ITL) at NIST promotes the U.S. economy and public welfare by providing technical leadership for the Nation’s measurement and standards infrastructure. ITL develops tests, test methods, reference data, proof of concept implementations, and technical analyses to advance the development and productive use of information technology (IT). ITL’s responsibilities include the development of management, administrative, technical, and physical standards and guidelines for the cost-effective security and privacy of other than national security-related information in Federal information systems. This document reports on ITL’s research, guidance, and outreach efforts in IT and its collaborative activities with industry, government, and academic organizations.

Abstract

Keywords

Adoption, barriers, market maturity, project maturity, organizational maturity, implementation, system modernization

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This document reflects the contributions and discussions by the membership of the NBD-PWG, co-chaired by Wo Chang (NIST ITL), Bob Marcus (ET-Strategies), and Chaitan Baru (San Diego Supercomputer Center; National Science Foundation). For all versions, the Subgroups were led by the following people: Nancy Grady (SAIC), Natasha Balac (SDSC), and Eugene Luster (R2AD) for the Definitions and Taxonomies Subgroup; Geoffrey Fox (Indiana University) and Tsegereda Beyene (Cisco Systems) for the Use Cases and Requirements Subgroup; Arnab Roy (Fujitsu), Mark Underwood (Krypton Brothers; Synchrony Financial), and Akhil Manchanda (GE) for the Security and Privacy Subgroup; David Boyd (InCadence Strategic Solutions), Orit Levin (Microsoft), Don Krapohl (Augmented Intelligence), and James Ketner (AT&T) for the Reference Architecture Subgroup; and Russell Reinsch (Center for Government Interoperability), David Boyd (InCadence Strategic Solutions), Carl Buffington (Vistronix), and Dan McClary (Oracle), for the Standards Roadmap Subgroup.

The editors for this document were the following:

* ***Version 1***: This volume resulted from Stage 2 work and was not part of the Version 1 scope.
* ***Version 2***: Russell Reinsch (Center for Government Interoperability) and Wo Chang (NIST)

Laurie Aldape (Energetics Incorporated) provided editorial assistance across all NBDIF volumes.

NIST SP1500-10, Version 2 has been collaboratively authored by the NBD-PWG. As of the date of this publication, there are over six hundred NBD-PWG participants from industry, academia, and government. Federal agency participants include the National Archives and Records Administration (NARA), National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), and the U.S. Departments of Agriculture, Commerce, Defense, Energy, Census, Health and Human Services, Homeland Security, Transportation, Treasury, and Veterans Affairs.

NIST would like to acknowledge the specific contributions[[1]](#footnote-2) to this volume, during Version 1 and/or Version 2 activities, by the following NBD-PWG members:

|  |  |  |
| --- | --- | --- |
| **David Boyd**  *InCadence Strategic Solutions*  **Frank Farance**  *Consultant*  **Geoffrey Fox**  *Indiana University*  **Nancy Grady**  *SAIC* | **Zane Harvey**  *QuantumS3*  **Haiping Luo**  *Department of the Treasury*  **Russell Reinsch**  *Center for Government Interoperability*  **Arnab Roy**  *Fujitsu* | **Mark Underwood**  *Krypton Brothers; Synchrony Financial*  **Gregor von Lasewski**  *Indiana University*  **Timothy Zimmerlin**  *Consultant* |

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Executive Summary

The NIST Big Data Public Working Group (NBD-PWG) Standards Roadmap Subgroup prepared this *NIST Big Data Interoperability Framework (NBDIF): Volume 9, Adoption and Modernization* to address ….

The NBDIF consists of nine volumes, each of which addresses a specific key topic, resulting from the work of the NBD-PWG. The nine NBDIF volumes, which can be downloaded from <https://bigdatawg.nist.gov/V2_output_docs.php>, are as follows:

* Volume 1, Definitions[[2]](#endnote-2)
* Volume 2, Taxonomies[[3]](#endnote-3)
* Volume 3, Use Cases and General Requirements[[4]](#endnote-4)
* Volume 4, Security and Privacy[[5]](#endnote-5)
* Volume 5, Architectures White Paper Survey[[6]](#endnote-6)
* Volume 6, Reference Architecture[[7]](#endnote-7)
* Volume 7, Standards Roadmap[[8]](#endnote-8)
* Volume 8, Reference Architecture Interfaces[[9]](#endnote-9)
* Volume 9, Adoption and Modernization[[10]](#endnote-10)

The *NBDIF* will be released in three versions, which correspond to the three development stages of the NBD-PWG work. The three stages aim to achieve the following with respect to the NIST Big Data Reference Architecture (NBDRA).

1. Identify the high-level Big Data reference architecture key components, which are technology-, infrastructure-, and vendor-agnostic.
2. Define general interfaces between the NBDRA components.
3. Validate the NBDRA by building Big Data general applications through the general interfaces.

Potential areas of future work for the Standards Roadmap Subgroup during Stage 3 are highlighted in Section 1.5 of this volume. The current effort documented in this volume reflects concepts developed within the rapidly evolving field of Big Data.

# Introduction

## Background

There is broad agreement among commercial, academic, and government leaders about the remarkable potential of Big Data to spark innovation, fuel commerce, and drive progress. Big Data is the common term used to describe the deluge of data in today’s networked, digitized, sensor-laden, and information-driven world. The availability of vast data resources carries the potential to answer questions previously out of reach, including the following:

* How can a potential pandemic reliably be detected early enough to intervene?
* Can new materials with advanced properties be predicted before these materials have ever been synthesized?
* How can the current advantage of the attacker over the defender in guarding against cyber-security threats be reversed?

There is also broad agreement on the ability of Big Data to overwhelm traditional approaches. The growth rates for data volumes, speeds, and complexity are outpacing scientific and technological advances in data analytics, management, transport, and data user spheres.

Despite widespread agreement on the inherent opportunities and current limitations of Big Data, a lack of consensus on some important fundamental questions continues to confuse potential users and stymie progress. These questions include the following:

* How is Big Data defined?
* What attributes define Big Data solutions?
* What is new in Big Data?
* What is the difference between Big Data and *bigger data* that has been collected for years?
* How is Big Data different from traditional data environments and related applications?
* What are the essential characteristics of Big Data environments?
* How do these environments integrate with currently deployed architectures?
* What are the central scientific, technological, and standardization challenges that need to be addressed to accelerate the deployment of robust, secure Big Data solutions?

Within this context, on March 29, 2012, the White House announced the Big Data Research and Development Initiative.[[11]](#endnote-11) The initiative’s goals include helping to accelerate the pace of discovery in science and engineering, strengthening national security, and transforming teaching and learning by improving analysts’ ability to extract knowledge and insights from large and complex collections of digital data.

Six federal departments and their agencies announced more than $200 million in commitments spread across more than 80 projects, which aim to significantly improve the tools and techniques needed to access, organize, and draw conclusions from huge volumes of digital data. The initiative also challenged industry, research universities, and nonprofits to join with the federal government to make the most of the opportunities created by Big Data.

Motivated by the White House initiative and public suggestions, the National Institute of Standards and Technology (NIST) has accepted the challenge to stimulate collaboration among industry professionals to further the secure and effective adoption of Big Data. As one result of NIST’s Cloud and Big Data Forum held on January 15–17, 2013, there was strong encouragement for NIST to create a public working group for the development of a Big Data Standards Roadmap. Forum participants noted that this roadmap should define and prioritize Big Data requirements, including interoperability, portability, reusability, extensibility, data usage, analytics, and technology infrastructure. In doing so, the roadmap would accelerate the adoption of the most secure and effective Big Data techniques and technology.

On June 19, 2013, the NIST Big Data Public Working Group (NBD-PWG) was launched with extensive participation by industry, academia, and government from across the nation. The scope of the NBD-PWG involves forming a community of interests from all sectors—including industry, academia, and government—with the goal of developing consensus on definitions, taxonomies, secure reference architectures, security and privacy, and, from these, a standards roadmap. Such a consensus would create a vendor-neutral, technology- and infrastructure-independent framework that would enable Big Data stakeholders to identify and use the best analytics tools for their processing and visualization requirements on the most suitable computing platform and cluster, while also allowing added value from Big Data service providers.

The *NIST Big Data Interoperability Framework* (NBDIF) will be released in three versions, which correspond to the three stages of the NBD-PWG work. The three stages aim to achieve the following with respect to the NIST Big Data Reference Architecture (NBDRA).

1. Identify the high-level Big Data reference architecture key components, which are technology, infrastructure, and vendor agnostic.
2. Define general interfaces between the NBDRA components.
3. Validate the NBDRA by building Big Data general applications through the general interfaces.

On September 16, 2015, seven NBDIFVersion 1 volumes were published (<http://bigdatawg.nist.gov/V1_output_docs.php>), each of which addresses a specific key topic, resulting from the work of the NBD-PWG. The seven volumes are as follows:

* Volume 1, Definitions
* Volume 2, Taxonomies
* Volume 3, Use Cases and General Requirements
* Volume 4, Security and Privacy
* Volume 5, Architectures White Paper Survey
* Volume 6, Reference Architecture
* Volume 7, Standards Roadmap

Currently, the NBD-PWG is working on Stage 2 with the goals to enhance the Version 1 content, define general interfaces between the NBDRA components by aggregating low-level interactions into high-level general interfaces, and demonstrate how the NBDRA can be used. As a result of the Stage 2 work, the following two additional NBDIF volumes have been developed.

* Volume 8, Reference Architecture Interfaces
* Volume 9, Adoption and Modernization

Version 2 of the NBDIF volumes, resulting from Stage 2 work, can be downloaded from the NBD-PWG website (<https://bigdatawg.nist.gov/V2_output_docs.php>). Potential areas of future work for each volume during Stage 3 are highlighted in Section 1.5 of each volume. The current effort documented in this volume reflects concepts developed within the rapidly evolving field of Big Data.

## Scope and Objectives of the Standards Roadmap Subgroup

The NBD-PWG Standards Roadmap Subgroup focused on forming a community of interest from industry, academia, and government, with the goal of developing a standards roadmap. The Subgroup’s approach included the following: (Ross, 2013)

* Collaborate with the other four NBD-PWG subgroups;
* Review products of the other four subgroups including taxonomies, use cases, general requirements, and reference architecture;
* Gain an understanding of what standards are available or under development that may apply Big Data;
* Perform a standards, gap analysis and document the findings;
* Document vision and recommendations for future standards activities;
* Identify possible barriers that may delay or prevent adoption of Big Data; and
* Identify a few areas where new standards could have a significant impact.

The goals of the Subgroup will be realized throughout the three planned phases of the NBD-PWG work, as outlined in Section 1.1.

Within the multitude of standards applicable to data and information technology (IT), the Subgroup focused on standards that: (1) apply to situations encountered in Big Data; (2) facilitate interfaces between NBDRA components (difference between Implementer [encoder] or User [decoder] may be nonexistent), (3) facilitate handling Big Data *characteristics*, and 4) represent a fundamental function.

## Report Production

The *NBDIF: Volume 9, Adoption and Modernization* is one of nine volumes, whose overall aims are to define and prioritize Big Data requirements, including interoperability, portability, reusability, extensibility, data usage, analytic techniques, and technology infrastructure in order to support secure and effective adoption of Big Data. The *NBDIF: Volume 9, Adoption and Modernization* arose from discussions during the weekly NBD-PWG conference calls. Topics included in this volume began to take form in Phase 2 of the NBD-PWG work and this volume represents the groundwork for additional content planned for Phase 3.

During the discussions, the NBD-PWG identified the need to examine the landscape of Big Data implementations, challenges to implementing Big Data systems, technological and organizational maturity, and considerations surrounding implementations and system modernization. Consistent with the vendor-agnostic approach of the NBDIF, these topics were discussed without specifications for a particular technology or product to provide information applicable to a broad reader base. The Standards Roadmap Subgroup will continue to develop these and possibly other topics during Phase 3. The current version reflects the breadth of knowledge of the Subgroup members. The public’s participation in Phase 3 of the NBD-PWG work is encouraged.

To achieve technical and high quality document content, this document will go through public comments period along with NIST internal review.

## Report Structure

Following the introductory material presented in Section 1, the remainder of this document is organized as follows:

* Section 2 examines the Big Data landscape at a high level
* Section 3 explores the panorama of Big Data adoption thus far and the technical and non-technical challenges faced by adopters of Big Data
* Section 4 considers the influence of maturity (market, project, and organizational) to adoption of Big Data
* Section 5 summarizes considerations when implementing Big Data systems or when modernizing existing systems to deal with Big Data

## Future Work on this Volume

A number of topics have not been discussed and clarified sufficiently to be included in Version 2. Topics that remain to be addressed in Version 3 of this document include the following:

* Areas where standards could have significant impact
* Technical challenges with data integration and preparation, specifically dealing with variables of different magnitudes
* Pathways for organizations to modernize to facilitate the successful transition from existing systems to more modern systems

# Landscape Perspective

Organizations face many challenges in the course of validating their existing integrations and observing the potential operational implications of the rapidly changing Big Data environment. Effectiveness is dependent on a clear understanding of new technologies. This section attempts to look at the industries and technologies related to Big Data and economic impacts by viewing them in context of the broader landscape.

One way of looking at this environment is to examine where the money has been spent. Table 1 shows a breakdown of spending by industry across the Asia-Pacific region. (Ross, 2013)

Table 1: Spending by Industry

|  |  |  |  |
| --- | --- | --- | --- |
| Industry | Spend | Certainty of Spend assumption | Adoption Rate |
| Telecommunications and media | $1.2b | Medium | Highest, 62% |
| Telecommunications and IT | $2b |  |  |
| Banking Financial services | $6.4b | Medium | 38% |
| Government and defense | $3b | High | 45% |
| IT, software, internet | $3b | Medium [for software] (DataRPM, 2015) | 57% |
| Natural resources, Energy, and utilities | $1b | Medium | 45% |
| Healthcare | $1b | Low | Slowest, 21% |
| Retail | $.8b | Low | Highest, 68% |
| Transportation, logistics | $.7b | Low |  |
| Biotechnology |  |  | Slowest, 21% |
| Pharmaceuticals |  |  | Slowest, 21% |
| Construction and real estate |  |  | 52% |
| Education |  | Low | 53% |
| Manufacturing and automotive |  | Low | 40% |

Other categories that could be included in Table 1 include life sciences, insurance, and professional services. In another report, the numbers of personnel working on Big Data projects were used to determine Big Data adoption rates. In this report, the IT, software and internet, and banking and financial services industries appear to have been early Big Data adopters, while the oil and energy, and healthcare and pharmaceutical industries adopted Big Data at a slower rate. (Naimat, 2016)

## 

# Adoption and Barriers

## Exploring Big Data Adoption

### Adoption by Industry

Adoption of Big Data systems has not been equilateral across all industries or sectors. While different industries have different potential to capture value, there are some common challenges that show up across all sectors could delay adoption of Big Data. A report by the US Bureau of Economic Analysis and McKinsey Global Institute (MGI) suggests that the most obvious barrier to leveraging Big Data is access to the data itself. (McKinsey & Company, 2011) The MGI report indicates a definite relationship between the ability to access data, and the potential to capture economic value, across all sectors / industries.

For example, the education industry is in the lowest percentile for availability of data, and consequently is also in the lowest 20% for exploiting economic value. The government sector, which is considered well positioned to benefit from Big Data, suffers from low access to data and may not fully realize the positive impacts of these technologies. (McKinsey & Company, 2011) Table 2 lists industries that have the best access to data and rate highest on MGI’s value index.

Table 2: Data Availability and Value Index from MGI Big Data Report

|  |  |
| --- | --- |
| Data Availability | Value Index |
| Manufacturing, top 20 percentile | Manufacturing, top 20 percentile |
| Utilities, top 20% | Utilities, top 20% |
| Information, top 20% | Information, top 40% |
| Healthcare and social assistance, top 40% | Healthcare and social assistance, top 20% |
| Natural resources, top 40% | Natural resources, top 20% |

### Functional Perspective of Adoption

Despite the obvious need for improved search technologies, very few organizations have implemented *real* search systems within their stack. AIIM polled 353 members of its global community and found that over 70% considered search to be essential or vital to operations, and equivalent in importance to both Big Data projects and TAR, yet the majority do not have a mature search function and only 18% have federated capability. (AIIM, 2014) There has been very little adoption of open source technologies (~15% on average) across small, medium, and large companies. Forecasts indicate reduced spending on do-it-yourself (DIY) built OS search apps.

## Technical and non-technical Barriers to adoption

As organizations attempt to implement Big Data systems, they can be faced with a multitude of challenges. Generally, these challenges are of two types: technical and non-technical. The technical challenges collection encompasses issues resulting from the hardware or software, and the interoperability between them, of a Big Data system. Technical challenges arise from various factors, which include functional components of a Big Data system, integration with those functional components, and the security of those components. Non-technical challenges involve issues surrounding the technical components of a Big Data system, but not considered a hardware or software issue. The non-technical barriers could include issues related to workforce preparedness and availability, high cost, too many or lack of regulations, and organizational culture.

Table 3 lists some of the more significant technical and non-technical barriers to adoption that were identified in the surveys. Particular industries or organizations could face barriers that are specific to their situation. Barriers listed in Table 3 were considered serious enough to adversely impact a large number of potential Big Data adoptions. Some barriers not listed in Table 3 may be specific to an industry or a particular organization.

Table 3: Non-Technical and Technical Barriers to Adoption

| Non-Technical Barriers | Technical Barriers |
| --- | --- |
| Lack of stakeholder definition and product agreement | Integration with existing infrastructure |
| Budget / expensive licenses | Security of systems |
| Lack of established processes to go from proof-of-concept to production systems | Cloud: concerns over liabilities, security, and performance |
| Compliance with privacy and regulations | Cloud: connectivity bandwidth is a most significant constraint |
| Inconsistent metadata standards | Cloud: Mesh, cell, and internet network components |
| Some silos of data and access restriction |  |
| Shifting from centralized stewardship toward decentralized and granular model |  |
| Legacy access methods present tremendous integration and compliance challenges |  |
| Proprietary, patented access methods have been a barrier to construction of connectors |  |
| Organizational maturity |  |
| Lack of practitioners with the ability to handle the complexity of software |  |

### Non-Technical Barriers

Frequently cited non-technical barriers are listed in Table 4 and include lack of stakeholder definition and product agreement, budget, expensive licenses, small return on investment (ROI) in comparison to Big Data project costs, and unclear ROI. Other major concerns are establishing processes to progress from proof-of-concept to production systems and compliance with privacy and other regulations.

In addition to technical considerations, there are also non-technical barriers to adoption of Big Data. For example, the adoption of access technologies involves non-technical organizational departments, for legal and security reasons, some silos of data and data access restriction policies are necessary. Poorly defined policies could result in inconsistent metadata standards within individual organizations, which can hinder interoperability.

Workforce issues also affect the adoption of Big Data. The lack of practitioners with the ability to handle the complexities of software, and integration issues with existing infrastructure are frequently cited as the most significant difficulties.

Table 4 lists several non-technical barriers to Big Data adoption and the amount of respondents that identified the Big Data barrier.

Table 4: Non-Technical Barriers to Adoption

| Non-Technical Barriers | Aggregate Surveys | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Category   * Sub-category | CDW | Accenture | Knowledgent | Hitachi | TDWI | Information Week |
| Difficulty developing an overall management program |  |  |  |  |  |  |
| Limited budgets; expensive licenses | 32% | 47% | 47% |  |  | 34% |
| Lack of stakeholder definition and product agreement |  |  | 45% |  |  | 40% |
| Difficulty establishing processes to go from POC to production |  |  | 43% |  |  |  |
| Compliance, privacy and regulatory concerns |  |  | 42% |  | 29% |  |
| * S&P challenge in regulation understanding or compliance |  |  |  |  |  |  |
| * Governance: monitoring; doc operating model |  |  |  |  |  |  |
| * Governance: ownership |  |  |  |  |  |  |
| * Governance: adapting rules for quickly changing end users |  |  |  |  |  |  |
| Difficulty operationalizing insights |  |  | 33% | 31% |  |  |
| Lack of access to sources |  |  |  |  |  |  |
| Silos: Lack of willingness to share; departmental communication |  |  |  | 36% |  |  |
| Healthcare Info Tech (HIT) |  |  |  |  |  |  |
| * Defining the data that needs to be collected | 35% |  |  |  |  |  |
| * Resistance to change | 30% |  |  |  |  |  |
| * Lack of industry standards | 21% |  |  |  |  |  |
| Lack of buy-in from management |  |  |  | 18% | 29% |  |
| Lack of compelling use case |  |  |  |  | 31% |  |
| No clear ROI |  |  |  |  |  | 36% |
| Lack of practitioners for complexity of software | 27% | 40% | 40% | 40% | 42% | 46% |

### Technical Barriers to Adoption

Technical barriers include a broad range of issues involving the hardware and software involved in Big Data systems. These issues affect every part of the Big Data system, as represented by the components and fabrics of the NBDRA. The *NBDIF: Volume 6, Reference Architecture* provides detailed discussion of the NBDRA and it functional components. Technical barriers have been identified in the literature, some which are summarized in Table 5. The amount of survey respondents that cited a particular barrier are expressed as a percentage in the table.

Table 5: Technical Barriers to Adoption

| Technical Barriers | Aggregate Surveys | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Category   * Subcategory | CDW | Accenture | Knowledgent | Hitachi | TDWI | Information Week |
| Reduced performance during concurrent usage |  |  |  |  |  |  |
| Integration problems with existing infrastructure |  | 35% | 35% |  |  |  |
| * Moving data from source to analytics environment NRT |  |  |  |  |  |  |
| * Blending internal & external data; merging sources | 45% |  |  |  |  |  |
| * Organization-wide view of data movement between apps |  |  |  |  |  |  |
| * Moving data between on-premise systems and clouds |  |  |  |  |  |  |
| * Hadoop data |  |  |  |  |  |  |
| Hadoop specific |  |  |  |  |  |  |
| * Backup and recovery |  |  |  |  |  |  |
| * Availability |  |  |  |  |  |  |
| * Performance at scale |  |  |  |  |  |  |
| * Lack of user friendly tools |  |  |  |  | 27% |  |
| * Security |  | 50% |  |  | 29% |  |
| Compliance, privacy, and regulatory concerns |  |  | 42% |  |  |  |
| * S&P securing deployments from hack |  |  |  |  |  |  |
| * S&P inability to mask, de-identify sensitive data |  |  |  |  |  |  |
| * S&P lack of fine control to support hetero user population |  |  |  |  |  |  |
| * Governance: auditing access; logging / tracking data lineage |  |  |  |  |  |  |
| Analytics layer technical misspecifications |  |  |  |  |  |  |
| Lack of suitable software |  |  |  | 42% |  |  |
| Lack of metadata management |  |  | 25% |  | 28% |  |
| Difficulty providing end users with self-service analytic capability |  |  | 33% |  |  |  |
| Complexity in providing business level context for understanding |  |  | 33% |  |  |  |

Parallel or congruent to market demand for self-service analytics application capabilities is a shift from centralized stewardship, toward a decentralized and granular model where user roles have structure for individual access rules. This shift presents barriers for search, including difficulties managing cloud sharing, mobile tech, and notetaking technologies. In addition, the cloud increases the challenges for governance.

Amongst privacy, security, and regulatory compliance concerns, governance appears to produce significant challenges. Often, privacy stakeholders may not need to be concerned with data in enterprise resource planning (ERP) systems; and security stakeholders may not need to be concerned with business intelligence and analytics systems; but governance stakeholders almost always need to be concerned with those systems, as well as with partner and financial data, and infrastructure components (e.g., database management system [DBMS] and networks). (Reference: Bowles)

The data that was captured in Table 5 was organized in a functional orientation. To assist in viewing some of the other large barriers to adoption, it is helpful to organize them by their domains. Two important domains are healthcare and cloud computing.

Within the healthcare domain, connectivity routes are especially important for interface interoperability of patient health information. Existing standards, such as Continuity of Care Record (CCR) and Continuity of Care Document (CCD) for clinical document exchange, provide a simple query and retrieve model for integration where care professionals can selectively transmit data. These models do not result in a horizontally interoperable system for holistic viewing platforms that can connect the query activities of independent professionals over time and over disparate systems regardless of the underlying infrastructure or operating system for maintaining the data (Fast Healthcare Interoperability Resources [FHIR] subscription web services approach). Additional standards work in this area could help alleviate the barrier.

In cloud implementations, cloud technologies have facilitated some aspects of Big Data adoption; however, challenges have arisen as the prevalence of cloud grows. Big Data challenges stemming from cloud usage include concerns over liabilities, security, and performance; the significant constraint of physical connectivity bandwidth; and interoperability of mesh, cell, and internet network components.

# 

# Maturity

## market maturity

This sub-section will discuss the market maturity of both hardware and software technologies related to Big Data systems. Technologies progress through a series of stages as they mature, which in broad terms are research and development (R&D), demonstration and deployment, and commercialization, in order of maturation development. As costs associated with both open source and commercial computing technologies fall drastically, it becomes easier for organizations to implement Big Data projects, increasing overall knowledge levels and adding to a tide effect where all boats in the marina are raised toward maturity. The following technologies represent some of the more recent advances into demonstration and deployment:

* Open source: Maturity of open source technologies is not as prevalent as many media reports would indicate. Open source distributed file systems are essentially still immature stacks, especially in smaller enterprises; although streaming and real-time technology adoption is growing at a fast rate. (Reference: O’Reilly)
* Unified architectures: Challenges persist in query planning. The age of Big Data applied a downward pressure on the use of standard indexes, reducing their use for data at rest. This trend is carried into adoption of unified architectures (Reference: Lambda), as unified architectures update indexes in batch intervals. An opportunity exists for open source technologies which are able to apply incremental indexing, to reduce updating costs and increase loading speeds for unified architectures.
* Open data: Some transformations are underway in the biology and cosmology domains, with new activity in climate science and materials science. (Reference: NIH, USGEO) Various agencies are considering mandating the management of curation and metadata activities in funded research projects. Metadata standards are frequently ranked as a significant technical issue. While agreeing on a local taxonomy snapshot is a large challenge for an organization, managing the difficulties of taxonomy dynamics (which are organizational issues) presents an even more challenging barrier.

The following technologies represent some of the more recent advances into commercialization.

* Infrastructure as a Service (IaaS): Applications receive a great deal of attention in articles written for business audiences. However, on the whole, the challenges in applications are proving less difficult to solve than challenges in infrastructure. IaaS is driving many opportunities for commercialization of technology.
* In-memory technologies: It is not always simple to distinguish between in-memory DBMS, in-memory analytics, and in-memory data grids. However, all in-memory technologies will provide a high benefit to organizations that have valid business use cases for adopting these technologies. In terms of maturity, in-memory technologies have essentially reached mainstream adoption and commercialization.
* Access technologies and information retrieval techniques: While access methods for traditional computing are in many cases brought forward into Big Data use cases, legacy access methods present tremendous integration and compliance challenges for organizations tackling Big Data. Solutions to the various challenges remain a work in progress. In some cases, proprietary, patented access methods have been a barrier to construction of connectors required for federated search and connectivity.
* Internal search: In one survey of organizations considering Big Data adoption, “Only 12% have an agreed search strategy, and only half of those have a specific budget.” (AIIM, 2014) The top two challenges to internal search seem to be a lack of available staff with the skills to support the function, and the organizations ability to dedicate personnel to maintain the related servers. Departments are reluctant to take ownership of the search function due to the problematic levels of the issues. The consensus amongst AIIM’s survey respondents was that the Compliance, Inspector General, or Records management department should actually be the responsible owner for the search function. An underlying problem persists in some larger organizations, however, where five or more competing search products can be found, due to small groups each using their own tools.
* Stream processing: Continued adoption of streaming data will benefit from technologies that provide the capability to cross reference (i.e., unify) streaming data with data at rest.

## project maturity

Big Data systems adoption often progresses along a path that can be cut into a series of distinctly different stages. In the first stage, an application is pilot tested in an ad-hoc project, where a small set of users run some quick and dirty models. This prototype system will likely be used primarily (or only) by those in the IT department and is often limited to storage and data transformation, and possibly some exploratory activity.

In the second stage, the project grows to department wide levels of adoption, where a wider range of user types work with the system. The project may expand beyond storage and integration functions and begin providing a function for one or two lines of business; perhaps performing unstructured data or predictive analysis. The project then faces its largest hurdle of the maturity process when it attempts to scale from departmental adoption, to an enterprise level project. Figure 1 depicts these stages and the significant hurdle from departmental to enterprise adoption.

Governance is one of the key obstacles to a project during this transition because an enterprise grade application will be required to have better defined user roles, better developed metadata policies and procedures, better control over information silo problems, and improvement in other related areas. In the enterprise setting the project must align more closely with organizational strategies that require higher orders of data quality, data protection, and partnership between IT and business departments.



Figure : Governance Gap Diagram

Information management roles and stewardship applications are two of the primary data management challenges organizations face with respect to governance. Within any single organization, data stewardship may take on one of a handful of particular models. In a data stewardship model that is function oriented or organization oriented, the components of the stewardship are often framed in terms of the lines of business or departments that use the data. For example, these departments might be Customer Service, Finance, Marketing, or Sales. All of these organization functions may be thought of as components of a larger enterprise process applications layer, supported by an organization wide standards layer.

In the early part of the fourth stage (Figure 1), the project has achieved integration with organizations’ governance protocols, metadata standards, and data quality management. Finally, a Big Data initiative evolves to a point where it can provide a full range of services including business user abstractions, and collaboration and data sharing capabilities.

## Organizational Maturity

Organizational maturity also is significant in Big Data adoption. Technical difficulties such as data integration and preparation are often reported as the greatest challenges to successful Big Data projects. However, non-technical issues such as change management, solution approach, or problem definition and framing are more likely to be greater challenges.

As stated in a report from IDC, “An organization’s ability to drive transformation with Big Data is directly correlated with its organizational maturity.” (IDC) In fact, organizational maturity is often the number one barrier to success of Big Data projects.

## Big Data Trends and Forecasts

In the early years of Big Data organizations approached projects with the goal to exploit internal data, leaving the challenges of dealing with external data for later. The usage of a *hub and spoke* architecture for data management emerged as a pattern in production environment implementations (Hopkins, Owens, & Keenan, 2013), which still relied heavily on ETL processes. The hub and spoke architecture provides multiple options for working with data in the hub, or for moving data out to the spokes for more specific task requirements; enabling for data persistence capabilities on one hand and data exposure (i.e., for analytics) capabilities on the other.

In 2017, in-memory, private cloud infrastructure, and complex event processing have reached the mainstream. Modern data science and machine learning are slightly behind but moving at a very fast pace to maturity.

Table 6 lists select technologies that are projected to mature in the near future and have a significant impact on the advancement of Big Data.

Table 6: Maturity Projections

|  |  |
| --- | --- |
| 2017 – 2020 | 2020 - 2025 |
| High performance message infrastructure | Internet of things |
| Search based analysis | Semantic web |
| PMML | Text and entity analysis |
|  | Integration |

An increase is expected in the application of semantic technologies for data enrichment. Semantic data enrichment is an area that has experienced successes in cloud deployments. Several applications of text analysis technology are driving the demand for standards development including fast moving consumer goods, fraud detection, and healthcare.

Integration is also an area of projected maturity growth. Increased usage is expected of lightweight iPaaS platforms. Use of application programming interfaces (APIs) for enabling microservices and mashup data from multiple sources are also anticipated to grow. Currently, there is a scarcity of general use interfaces that are capable of supporting diverse data management requirements, the capability to work with container frameworks, data APIs, and metadata standards. Demand is increasing for interfaces with flexibility to handle heterogeneous user types, each having unique conceptual needs.

# Considerations for Implementation and Modernization

## Implementation

Characteristics of a Big Data project implementation depend on the needs and capabilities of the particular organization undertaking the effort. This section attempts to provide some high-level issues for deliberation during the Big Data project planning stage. This is not intended to be a prescription covering the entire range or depth of considerations that an organization may face, but rather an initial list to supplement with project specific concerns. During the planning phase, Big Data project considerations could include the following:

* Data quality: Consider the level of quality that will be required from the data model. As data quality increases, cost increases. A minimum viable quality of data, which will provide desired results, should be determined.
* Data access: Many factors can affect data access including organizational cultural challenges and security and privacy compliance. Cultural challenges are unique to each project but many are alleviated with sufficient support from upper management (e.g., corporate officers, influential advocates). Security and privacy affects multiple areas in a Big Data project including data access. Additional information on security and privacy considerations are provided in the *NBDIF: Volume 4, Security and Privacy* document.
* Component interoperability: For a complicated system, a comprehensive appraisal of system component interoperability can be critical. Advantages of commercial products are frequently lauded while the limitations, dependencies, and deficiencies are often not obvious. Exploration of component interoperability during the planning phase could prevent significant issues during later phases of Big Data projects.
* Potential bottlenecks: Projects requiring high performance often expose storage and network bottlenecks.
* For search oriented projects: Organizations should strive to set a balance between governance and retrieval, determine ownership (i.e., departmental responsibility) for the function, aim for unified or single point search capability; and, unless the organization is a strong IT company, identify needed outsourced expertise.

## System Modernization

An organization preparing to develop a Big Data system will typically consider one of two possible directions for modernization. For simplification, these two directions will be referred to as Augmentation and Replacement, herein. Each of these two modernization directions have unique advantages and disadvantages. The following summarizes the two directions:

* Augmentation: This direction involves updating to a Big Data system by augmenting the supporting architecture. Advantages of updating the supporting architecture include incorporation of more mature technologies amidst the stack and flexibility in the implementation timeline. Augmentation allows for a phased implementation that can be stretched out over more than one fiscal budget year.
* Replacement: This direction involves updating to a Big Data system by replacing the existing system with an entirely new system. Modernizing an existing system by replacing the whole architecture has notable disadvantages. In comparison to the augmentation approach, the level of change management required when replacing entire systems is significantly higher. One advantage of complete system replacement is reduced compatibility problems with legacy systems. Partial modernizations, by replacing a portion of the existing system, are also possible. However, the same advantages and disadvantages of complete system replacement may not apply.

Table 7 summarizes the advantages and disadvantages of the two directions for system modernization.

Table 7: Possible Directions for Modernization

|  |  |
| --- | --- |
| Advantages and Disadvantages of the Two Directions for Modernization | |
| Augmentation | |
| Advantages   * Phased approach * Not entirely immature stack of technology | **Disadvantages**   * TBD |
| Replacement | |
| Advantages   * Reduced compatibility problems with legacy systems | **Disadvantages**   * Longer development cycle * Increased change management * Less mature technologies |

Once system augmentation or replacement has been elected, a method of implementation can be chosen. Figure 2 diagrams a decision situation, commonly referred to as *build or buy* (or outsource) that organizations face when modernizing to a Big Data system. In the build, or DIY scenario, the organization may modify their existing system or build an entirely new system separate of the existing system. One of the largest barriers organizations face when building their own systems is the scarcity of engineers with the skillset covering the newer technologies such as streaming or near real time analysis.



Figure : New System Implementation

If the DIY implementation is erected concurrent to the existing system, the organization is required to operate two systems for the length of time it will take to get the new system running and migrate data or combine components.

The alternative to the DIY scenario is for the organization to buy or rent a new Big Data system. Renting usually refers to cloud solutions. Advantages to buying or renting include the ease of scale and not having to operate congruent systems (or possibly not having to modify an existing system).

Hybrid parallel systems are those that are not 100% integrated with the existing system. For example, organizations can use the cloud for storage but develop their own applications. One disadvantage is the high cost of moving data to the cloud. Developing standards for hybrid implementations should accelerate the adoption and interoperability of analytics applications.

Challenges exist with any of the implementation routes (DIY, buy or rent new system, or hybrid parallel systems). For example, data cleansing, and systems plumbing are persistent hurdles no matter which type of project is undertaken. (Reference:Neef; IBM)

In every case, lower level or lower layer components of the system must be considered as equally (if not more) important as analysis or analytics functions. Future work on this volume may include improved coverage of an entire system modernization.

In addition to the modernization of complete systems, the modernization of analytics applications will be considered—specifically with respect to machine learning. Some motivations for modernizing analytics include the following:

* Improved monitoring and reporting: Basic, descriptive business intelligence may be improved though use of Big Data systems.
* Improved diagnostics, forecasting, and predictive analysis: The term predictive analysis is often used to refer to analysis which is not exactly predictive in the common sense of the word.
* Enriched decision making: This function comprises 70% of the demand for analytics in 2017. (Reference: FICO) While operational decisions can be rule based, not involving analytics, strategic decisions are optimization tasks.

Figure 3 very much over-simplifies some of the questions related to system capability that an organization may need to consider when planning their own system, but it does demonstrate how project requirements can drive decision making. The list of choices presented is not intended to be comprehensively complete. Inclusion is not an endorsement for usage, and no solutions have been intentionally excluded.



Figure : Requirement Decision Tree

After the scalability and latency requirements are considered as shown in Figure 3, the systems planning process will require continued consideration on whether machine learning is necessary. Figures 4, 5, and 6 map the workflow of the machine learning decision trees and show the decision points in the application of machine learning algorithms. Tables 8, 9, 10, and 11 list specific algorithms for each algorithm subgroup.

Figure : Machine Learning Algorithm Application Workflow

Figure 4 shows the decision steps for application of a machine learning algorithm including the input preparation phase (e.g., feature engineering, data cleaning, transformations, scaling). Figures 5 and 6 expand on algorithm choices for each problem subclass. Tables 8 and 9 continue from Figure 5 to provide additional information for the regression or classification algorithms. Tables 10 and 11 provide additional information on the unsupervised algorithms and techniques shown in Figure 6.

Figure : Supervised Machine Learning Algorithms

Figure : Unsupervised or Reinforcement Machine Learning Algorithms

Supervised learning problems involve data sets that have the feature which is trying to be predicted measured for all observations or a subset of all observations (semi-supervised learning). The measurements for the feature which is trying to be predicted by the machine learning model are called labels. In supervised learning problems, the labeled data is used to train the model to produce accurate predictions.

Supervised learning problems can be classified into algorithm two sub groups: regression or classification. Regression algorithms predict a continuous variable (a number), and classification algorithms predict a category from a finite list of possible categories. Table 8 and 9 compare supervised learning regression algorithms using four categories and supervised learning classification algorithms using the same four categories.

Table 8: Supervised Learning Regression Algorithms

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Name | Training Speed | Interpretability | Pre-Processing | Other Notes |
| Linear Regression | Fast | High | Centering and Scaling, Remove Highly Correlated Predictors | Speed at the expense of accuracy |
| Decision Tree | Fast | Medium |  | Speed at the expense of accuracy |
| Random Forest | Fast | Medium |  | Fast and accurate |
| Neural Network | Slow | Low | Centering and Scaling, Remove Highly Correlated Predictors | Accurate |
| K Nearest Neighbors | Fast | Low |  | Scales over medium size datasets |
| Ridge Regression | Fast | High | Centering and Scaling |  |
| Partial Least Squares | Fast | High | Centering and Scaling |  |
| Cubist | Slow | Low |  |  |
| MARS | Fast | Medium |  |  |
| Bagged / Boosted Trees | Fast | Low |  | Accurate, large memory requirements |

Table 9: Supervised Learning Classification Algorithms

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Name | Training Speed | Interpretability | Pre-Processing | Other Notes |
| Support Vector Machine | Slow | Low | Centering and Scaling | Speed at the expense of accuracy |
| Logistic Regression | Fast | High | Centering and Scaling, Remove Highly Correlated Predictors | Speed at the expense of accuracy |
| Decision Tree | Fast | Medium |  | Speed at the expense of accuracy |
| Random Forest | Slow | Medium |  | Accurate |
| Naïve Bayes | Fast | Low |  | Scales over vary large datasets. Speed at the expense of accuracy |
| Neural Network | Slow | Low | Centering and Scaling, Remove Highly Correlated Predictors |  |
| K Nearest Neighbors | Fast | Low |  | Scales over medium size datasets |
| Ridge Regression | Fast | High | Centering and Scaling |  |
| Nearest Shrunken Centroids | Fast | Medium |  |  |
| MARS | Fast | High |  |  |
| Bagged / Boosted Trees | Slow | Low |  | Accurate |

Unsupervised learning problems do not have labeled data and can be classified into two subgroups: clustering algorithms and dimensionality reduction techniques. Clustering algorithms attempt to find underlying structure in the data by determining groups of similar data. Dimensionality reduction algorithms are typically used for pre-processing of data sets prior to the application of other algorithms. Table 10 lists common clustering algorithms and Table 11 lists common dimensionality reduction techniques.

Table 10: Unsupervised Clustering Algorithms

| Name | Pre-Processing | Interpretability | Notes |
| --- | --- | --- | --- |
| K -means | Missing value sensitivity, Centering and Scaling | Medium | Scales over large datasets for clustering tasks, must specify number of clusters (k) |
| Fuzzy c-means |  |  | Must specify number of clusters (k) |
| Gaussian | Specify k for probability tasks |  | Must specify number of clusters (k) |
| Hierarchical |  |  | Must specify number of clusters (k) |
| DBSCAN |  |  | Do not have to specify number of clusters (k) |

While technically dimension reduction may be a pre-processing technique, which transforms predictors, usually driven for computational reasons, some consider dimensionality reduction (or data reduction) techniques a class of unsupervised algorithms because they are also a solution for un-labeled data.

In that these methods attempt to *reduce* the data by capturing as much information as possible with a smaller set of predictors, they are very important for Big Data. Many machine learning models are sensitive to highly correlated predictors, and dimensionality reduction techniques are necessary for their implementation. Dimensionality reduction methods can increase interpretability and model accuracy, and reduce computational time, noise, and complexity.

Table 11: Dimensionality Reduction Techniques

|  |  |  |
| --- | --- | --- |
| Name | Interpretability | Notes |
| Principal Component Analysis (PCA) | Low | Scales to medium or large datasets |
| Correlation Filters |  |  |
| Linear Discriminant Analysis (LDA) |  |  |
| Generalized Discriminant Analysis (GDA) |  |  |
| Backward Feature Elimination |  |  |
| Singular Value Decomposition (SVD) |  |  |

It should be noted that while a wide array of algorithms have been classified in the preceding tables, a technique called ensemble modeling is widely used to combine the results of different types of algorithms to produce a more accurate result. Ensemble methods are learning algorithms that take a weighted vote of their different model’s predictions to produce a final solution. In practice, many applications will use an ensemble model to maximize predictive power.

2. Acronyms

API application programming interface

CCD Continuity of Care Document

CCR Continuity of Care Record

DBMS database management system

DIY do-it-yourself

ERP enterprise resource planning

FHIR Fast Healthcare Interoperability Resources

HIT Healthcare Info Tech

IaaS Infrastructure as a Service

iPaaS Integration Platform as a Service

IT information technology

ITL Information Technology Laboratory at NIST

MGI McKinsey Global Institute

NBDIF NIST Big Data Interoperability Framework

NBD-PWG NIST Big Data Public Working Group

NBDRA NIST Big Data Reference Architecture

NIST National Institute of Standards and Technology

OS operating system

R&D research and development

ROI return on investment

TAR

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