



# EDISON Data Science Framework:

## Part 2. Data Science Body of Knowledge (DS-BoK)

### Pre-Release 3

EDISON Community Initiative  
(Maintaining the H2020 EDISON project outcome)

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## Executive summary

The initial definition of the EDISON Data Science Framework (EDSF) has been done in the Horizon2020 Project EDISON (Grant 675419) that produced Release 1 (2016 and Release 2 (2017). Currently, EDSF is maintained by the EDISON Community initiative that is coordinated by the University of Amsterdam. The new EDSF Release 3 is the product of the wide community of academicians, researcher and practitioners that are practically involved into Data Science and Data Analytics education and training, competences and skills management in organisations, and standardisation in the area of competences, skills, occupations and digital technologies.

The EDISON Data Science Framework (EDSF) includes such components as Data Science Competence Framework (CF-DS), Data Science Body of Knowledge (DS-BoK) and Data Science Model Curriculum (MC-DS), and Data Science Professional Profiles (DSPP). The EDSF provides a conceptual basis for the Data Science Profession definition, targeted education and training, professional certification, organizational capacity building, and organisation and individual skills management and career transferability.

The definition of the Data Science Body of Knowledge provides a basis for defining the Data Science Model Curriculum and further can be used for the Data Science professional certification.

The presented DS-BoK defines six groups of Knowledge Areas (KAG) that are linked to the identified competence groups defined in CF-DS: KAG-DSA Data Analytics; KAG-DSDM Data Management, KAG-DSE Data Science Engineering, KAG-DSRMP Research Methods and Project Management; and KAG-DSBPM Business Process Management. Knowledge Areas are composed of a number of Knowledge Units (KU) which are currently lowest component of the DS-BoK. Defining the domain knowledge groups both for science and business will be a subject for further DS-BoK development in tight cooperation with domain specialists.

The proposed EDSF and DS-BoK in particular are intended to provide a guidance and a basis for universities to define their Data Science curricula and courses selection, on one hand, and for companies to better define a set of required competences and skills for their specific industry domain in their search for Data Science talents, on the other hand.

The EDSF documents are available for public discussion at the EDISON Community initiative at <https://github.com/EDISONcommunity/EDSF/wiki/EDSFhome>

## TABLE OF CONTENTS

1	Introduction.....	6
2	EDISON Data Science Framework.....	7
3	Overview of BoKs relevant to DS-BoK .....	9
3.1	ACM Computer Science Body of Knowledge (CS-BoK) .....	9
3.2	ICT professional Body of knowledge ICT-BoK .....	10
3.3	Software Engineering Body of Knowledge (SWEBOK) .....	10
3.4	Business Analysis Body of Knowledge (BABOK) .....	11
3.5	Data Management Body of Knowledge (DM-BoK) by DAMAI .....	12
3.6	Project Management Professional Body of Knowledge (PM-BoK) .....	12
4	Data Science Body of Knowledge (DS-BoK) definition.....	14
4.1	General Approach and Structure of DS-BoK .....	14
4.2	Data Science Body of Knowledge Areas and Knowledge Units .....	14
5	Conclusion and further developments .....	28
5.1	Summary of the presented development.....	28
5.2	Further developments to formalize CF-DS and DS-BoK.....	28
6	References .....	29
	Acronyms .....	30
	Appendix A. Overview of Bodies of Knowledge relevant to Data Science .....	31
	A.1. ICT Professional Body of knowledge .....	31
	A.2. Data Management Professional Body of knowledge .....	32
	A.3. Project Management Professional Body of knowledge .....	34
	Appendix B. Subset of ACM/IEEE CCS2012 for Data Science (as defined in DS-BoK Release 1) .....	37
	B.1. ACM Classification Computer Science (2012) structure and Data Science related Knowledge Areas .....	37

## 1 Introduction

Data Science Competence Framework (CF-DS) is a part of the EDISON Data Science Framework (EDSF) that comprise of the following documents: Data Science Competence Framework (CF-DS) [1], Data Science Body of Knowledge (DS-BoK) [2], Model Curriculum (MC-DC) [3], and Data Science Professional Profiles (DSPP) [4].

This document presents the Data Science Body of Knowledge (DS-BoK) Release 3 revised and updated after the Release 2 publication in July 2017, based on feedback from multiple practical implementations by champion universities that cooperated with the EDISON project and incorporating comments and suggestions from experts and community discussions. The Release 3 revision and update was discussed and approved at the EDSF Release 3 Design Workshop on 18-19 July 2018 in Amsterdam<sup>1</sup>.

The main goal of the proposed Data Science Body of Knowledge is a to propose a consistent Data Science Body of Knowledge that would consolidate existing scattered standards, practices and resources and answer requirements from multiple stakeholders to create a sustainable Data Science competences and skills management ecosystem,

The presented DS-BoK definition is based on overview and analysis of existing bodies of knowledge that are relevant to required competences and knowledge for Data Science and required to fulfil the identified in CF-DS competences and skills.

The presented DS-BoK defines six groups of Knowledge Areas (KAG) that are linked to the identified competence groups defined in CF-DS: KAG-DSA Data Analytics; KAG-DSDM Data Management, KAG-DSE Data Science Engineering, KAG-DSRMP Research Methods and Project Management; and KAG-DSBPM Business Process Management. Knowledge Areas are composed of a number of Knowledge Units (KU) which are currently lowest component of the DS-BoK. Defining the domain knowledge groups both for science and business will be a subject for further DS-BoK development in tight cooperation with domain specialists.

DS-BoK incorporates best practices in Computer Science and domain specific BoK's and includes KAs and KUs defined where possible based on the Classification Computer Science (CCS2012), components taken from other BoKs and proposed new KAs/KUs to incorporate new technologies used in Data Science and their recent developments.

The definition of the Data Science Body of Knowledge provides a basis for defining the Data Science Model Curriculum and further for the Data Science professional certification.

DS-BoK is maintained by the University of Amsterdam as a part of the community shared EDISON Initiative. Further work will be required to develop consistent DS-BoK that can be accepted by academic community and professional training community.

The presented document has the following structure. Section 2 provides an overview of the EDISON Data Science Framework and related components of the Data Science professional ecosystem. Section 3 provides overview of existing BoKs related to Data Science knowledge areas. Section 3 also includes other important components for the DS-BoK definition such as data lifecycle management models, scientific methods, and business process management lifecycle models. Section 4 described the proposed DS-BoK structure and provides the initial definition of the DS-BoK. Section 5 provides summary of the achieved results and suggests further development.

Appendices to this document contain important supplementary information: detailed information about reviewed bodies of knowledge related to identified Data Science knowledge areas; taxonomy of the Data Science knowledge areas and scientific disciplines built as a subset of the ACM CCS (2012) classification.

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<sup>1</sup> [https://github.com/EDISONcommunity/EDSF/wiki/\(1\)-EDSF-Release-3-Design-Workshop-18-19-July-2018-\(UvA\)](https://github.com/EDISONcommunity/EDSF/wiki/(1)-EDSF-Release-3-Design-Workshop-18-19-July-2018-(UvA))

## 2 EDISON Data Science Framework

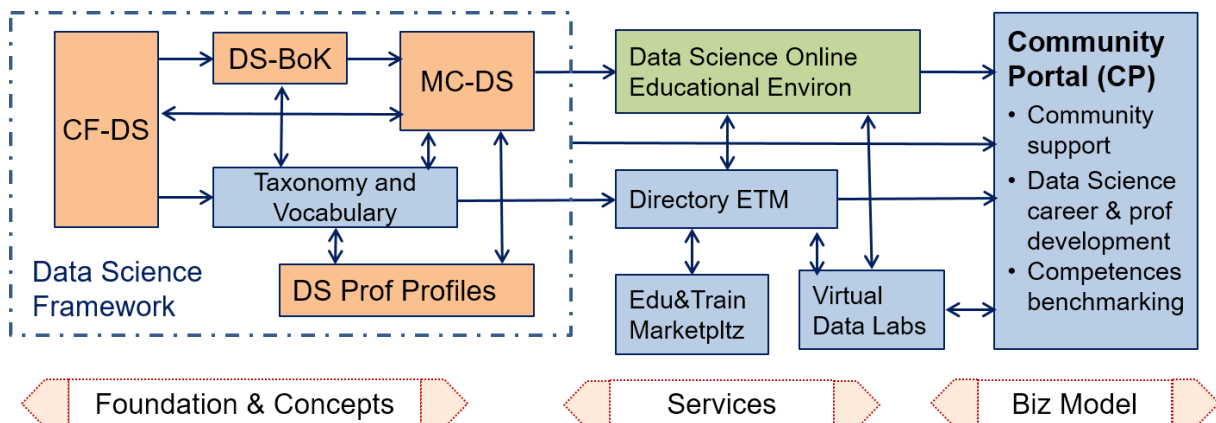
The EDISON Data Science Framework provides a basis for the definition of the Data Science profession and enabling the definition of the other components related to Data Science education, training, organisational roles definition and skills management, as well as professional certification.

Figure 1 below illustrates the main components of the EDISON Data Science Framework (EDSF) and their inter-relations that provides conceptual basis for the development of the Data Science profession:

- CF-DS – Data Science Competence Framework [1]
- DS-BoK – Data Science Body of Knowledge (this document [2])
- MC-DS – Data Science Model Curriculum [3]
- DSPP - Data Science Professional profiles and occupations taxonomy [4]
- Data Science Taxonomy and Scientific Disciplines Classification

The proposed framework provides basis for other components of the Data Science professional ecosystem<sup>2</sup> such as

- EDISON Online Education Environment (EOEE)
- Education and Training Directory and Marketplace
- Data Science Community Portal (CP) that also includes tools for individual competences benchmarking and personalized educational path building
- Certification Framework for core Data Science competences and professional profiles



**Figure 1 EDISON Data Science Framework components.**

The CF-DS provides the overall basis for the whole EDSF. The core CF-DS includes common competences required for successful work of Data Scientist in different work environments in industry and in research and through the whole career path. The future CF-DS development will include coverage of the domain specific competences and skills and will involve domain and subject matter experts.

The DS-BoK defines the Knowledge Areas (KA) for building Data Science curricula that are required to support identified Data Science competences. DS-BoK is organised by Knowledge Area Groups (KAG) that correspond to the CF-DS competence groups. Knowledge Areas are composed of a number Knowledge Units (KU) which are currently lowest component of the DS-BoK. DS-BoK incorporates best practices in Computer Science and domain specific BoK's and includes KAs and KUs defined where possible based on the Classification Computer Science (CCS2012) [6], components taken from other BoKs and proposed new KAs/KUs to incorporate new technologies used in Data Science and their recent developments.

<sup>2</sup> The described Data Science- ecosystem components are defined and piloted in the EDISON project and constitute the project legacy that can be re-used and followed by the community. EDISON Project Deliverable D3.2 EDISON Online Education Environment, August 2016 [15]

The MC-DS is built based on CF-DS and DS-BoK where Learning Outcomes (LO) are defined based on CF-DS competences and Learning Units are mapped to Knowledge Units in DS-BoK. Three mastery (or proficiency) levels are defined for each Learning Outcome to allow for flexible curricula development and profiling for different Data Science professional profiles. The proposed Learning Outcomes are enumerated to have direct mapping to the enumerated competences in CF-DS.

The DSPP are defined as an extension to European Skills, Competences, Qualifications and Occupations (ESCO) taxonomy [16] using the ESCO top classification groups. DSPP definition provides an important instrument to define effective organisational structures and roles related to Data Science positions and can be also used for building individual career path and corresponding competences and skills transferability between organisations and sectors.

The Data Science Taxonomy and Scientific Disciplines Classification will serve to maintain consistency between four core components of EDSF: CF-DS, DS-BoK, MC-DS, and DSP profiles. To ensure consistency and linking between EDSF components, all individual elements of the framework are enumerated, in particular: competences, skills, and knowledge topics in CF-DS, knowledge groups, areas and units in DS-BoK, learning outcomes and learning units in MC-DS, and professional profiles in DSPP.

It is anticipated that successful acceptance of the proposed EDSF and its core components will require standardisation and interaction with the European and international standardisation bodies and professional organisations. This work is being done as a part of the ongoing EDSF dissemination and sustainability activity.

The EDISON Data Science professional ecosystem illustrated in Figure 1 uses core EDSF components to specify the potential services that can be offered for the professional Data Science community and provide basis for the sustainable Data Science competences and skills management by organisations, in particular in conditions of emerging Industry 4.0, growing digitalisations and Artificial Intelligence development. As an example of practical use, CF-DS and DS-BoK can be used for individual competences and knowledge benchmarking and play instrumental role in constructing personalised learning paths and professional (up/re-) skilling programs based on MC-DS.



### 3 Overview of BoKs relevant to DS-BoK

The following BoK's have been reviewed to provide a basis for initial definition of the DS-BoK:

- ACM Computer Science Body of Knowledge (ACM CS-BoK) [6, 7, 8]
- ICT professional Body of Knowledge (ICT-BoK) [9]
- Business Analytics Body of Knowledge (BABOK) [10]
- Software Engineering Body of Knowledge (SWEBOK) [11]
- Data Management Body of Knowledge (DM-BoK) by Data Management Association International (DAMA) [12]
- Project Management Professional Body of Knowledge (PM-BoK) [13]

The following sections provide a short description and analysis of each body of knowledge. These allowed to identify what components of the existing BoKs can be re-used to construct a consistent Data Science Body of Knowledge that should support competence groups defined in CF-DS. The DS-BoK should also reflect the data-lifecycle management where different organisational roles, functions, competences and knowledge are required.

The presented analysis allowed to identify what existing BoK's can be used in the DS-BoK definition or mapped to ensure knowledge transferability and education programmes compatibility. From this initial analysis the relevant best practices have been identified to structure the DS-BoK and provide a basis for defining the Data Science professional certification scheme.

#### 3.1 ACM Computer Science Body of Knowledge (CS-BoK)

In the ACM-CS2013-final report [7, 8] the Body of Knowledge is defined as a specification of the content to be covered in a curriculum that serves as an implementation of the BoK. The ACM-BoK describes and structures the knowledge areas needed to define a curriculum in Computer Science, it includes 18 Knowledge Areas (where 6 KAs are newly introduced in ACM CS2013):

AL - Algorithms and Complexity  
AR - Architecture and Organization  
CN - Computational Science  
DS - Discrete Structures  
GV - Graphics and Visualization  
HCI - Human-Computer Interaction  
IAS - Information Assurance and Security (new)  
IM - Information Management  
IS - Intelligent Systems  
NC - Networking and Communications (new)  
OS - Operating Systems  
PBD - Platform-based Development (new)  
PD - Parallel and Distributed Computing (new)  
PL - Programming Languages  
SDF - Software Development Fundamentals (new)  
SE - Software Engineering  
SF - Systems Fundamentals (new)  
SP - Social Issues and Professional Practice

Knowledge areas should not directly match a particular course in a curriculum (this practice is strongly discouraged in the ACM report), often courses address topics from multiple knowledge areas. The ACM-CS2013-final report distinguish between two type of topics: Core topics subdivided into "Tier-1" (that are mandatory for each curriculum) and "Tier-2" (that are expected to be covered at 90-100% with minimum advised 80%), and elective topics. The ACM classification suggests that a curriculum should include all topics in Tier-1 and all or almost the topics in Tier 2. Tier 1 and Tier 2 topics are defined differently for different programmes and specialisations. To be complete a curriculum should cover, in addition to the topics of Core Tier 1 and 2, significant amount of elective material. The reason for such a hierarchical approach to the structure of the Body of Knowledge is a useful way to group related information, not as a structure for organizing material into courses.

The ACM for computing Education in Community Colleges [9] defines a BoK for IT outcome-based learning/education which identifies 6 technical competency areas and 5 work-place skills. While the technical areas are specific to IT competences and specify a set of demonstrable abilities of graduates to perform some specific functions, the so called work-place skills describe the ability the student/trainee to:

- (1) function effectively as a member of a diverse team,
- (2) read and interpret technical information,
- (3) engage in continuous learning,
- (4) professional, legal, and ethical behaviour, and
- (5) demonstrate business awareness and workplace effectiveness

The CS-BoK uses ACM Computing Classification System (CCS) which is standard and widely accepted what makes it a good basis for using it as a basis for building DS-BoK and providing necessary extensions/KAs related to identified Data Science competence groups (see section 3.4) which majority require background knowledge components from the general CS-BoK.

### 3.2 ICT professional Body of knowledge ICT-BoK

The ICT-BoK is an effort promoted by the European Commission, under the eSkills initiative (<http://eskills4jobs.ec.europa.eu/>) to defines and organises the core knowledge of the ICT discipline. In order to foster the growth of digital jobs in Europe and to improve ICT Professionalism a study has been conducted to provide the basis of a “Framework for ICT professionalism” (<http://ictprof.eu/>). This framework consists of four building blocks which are also found in other professions:

- i) body of knowledge (BoK);
- ii) competence framework;
- iii) education and training resources; and
- iv) code of professional ethics.

A competence framework already exists and consists in the e-Competence Framework (now in its version 3.0 and promoted by CEN). However, an ICT Body of Knowledge that provides the basis for a common understanding of the foundational knowledge an ICT professional should possess, is not yet available.

The ICT-BoK is suggested to be structured in 5 *Process Groups*, defining the various phases of the project development or organisational workflow: *Initiating, Planning, Executing, Monitoring and Controlling, Closing*.

The ICT-BoK aims at informing about the level of knowledge required to enter the ICT profession and acts as the first point of reference for anyone interested in working in ICT. Even if the ICT-BoK does not refer to Data Science competences explicitly the identified ICT processes can be applied to data management processes both in industry and academia in the context of well-defined and structured projects.

### 3.3 Software Engineering Body of Knowledge (SWEBOK)

The Software Engineering Body of Knowledge (SWEBOK) is an international standard ISO/IEC TR 19759:2015<sup>3</sup> specifying a guide to the generally accepted Software Engineering Body of Knowledge. The Guide to the Software Engineering Body of Knowledge (SWEBOK Guide) has been created through cooperation among several professional bodies and members of industry and is published by the IEEE Computer Society. The standard can be accessed freely from the IEEE Computer Society (<http://www.computer.org/web/swebok/v3>).<sup>4</sup>

The published version of SWEBOK V3 has the following 15 knowledge areas (KAs) within the field of software engineering: and 7 additional disciplines are recognized as linked and providing important background knowledge that are beneficial for Software Engineering:

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<sup>3</sup> ISO/IEC TR 19759:2015 Software Engineering - Guide to the software engineering body of knowledge (SWEBOK)

<sup>4</sup> SWEBOK can be also accessed from <http://www4.ncsu.edu/~tjmenzie/cs510/pdf/SWEBOKv3.pdf>

#### SWEBOK Knowledge Areas

- Software requirements
- Software design
- Software construction
- Software testing
- Software maintenance
- Software configuration management
- Software engineering management
- Software engineering process
- Software engineering models and methods
- Software quality
- Software engineering professional practice
- Software engineering economics
- Computing foundations
- Mathematical foundations
- Engineering foundations

#### Additional linked disciplines

- Computer engineering
- Systems engineering
- Project management
- Quality management
- General management
- Computer science
- Mathematics

### 3.4 Business Analysis Body of Knowledge (BABOK)

*BABOK Guide* was first published by International Institute of Business Analysis (IIBA) as a draft document version 1.4, in October 2005, for consultation with the wider business analysis and project management community, to document and standardize generally accepted business analysis practices. Current version 3 was released in April 2015.

The Business Analysis Body of Knowledge provides interesting example of business oriented body of knowledge that covers important for Data Science knowledge domain. BABOK is published in a Guide to the Business Analysis Body of Knowledge (BABOK Guide). It is the globally recognized standard for the practice of business analysis. BABOK Guide reflects the collective knowledge of the business analysis community and presents the most widely accepted business analysis practices.

BABOK Guide recognizes and reflects the fact that business analysis is continually evolving and is practiced in a wide variety of forms and contexts. It defines the skills, knowledge, and competencies required to perform business analysis effectively. It does not describe the processes that people will follow to do business analysis.

BABOK Guide includes chapters on:

- Business Analysis Key Concepts: define important terms that are the foundation of the practice of business analysis.
- Knowledge Areas: represents the core content of *BABOK Guide* and contain the business analysis tasks that are used to perform business analysis.
- Underlying Competencies: describes the behaviours, characteristics, knowledge, and personal qualities that help business analysts be effective in their job.
- Techniques: describes 50 of the most common techniques used by business analysts.
- Perspectives (new to version 3): describes 5 different views of business analysis (Agile, Business Intelligence, Information Technology, Business Architecture, and Business Process Management).

BABOK Guide organises business analysis tasks within 6 knowledge areas. The knowledge areas logically organize tasks but do not specify a sequence, process, or methodology. Each task describes the typical knowledge, skills, deliverables, and techniques that the business analyst requires to be able to perform those tasks competently.

The following knowledge areas of BABOK Guide are defined:

- Business Analysis Planning and Monitoring: describes the tasks used to organize and coordinate business analysis efforts.

- Elicitation and Collaboration: describes the tasks used to prepare for and conduct elicitation activities and confirm the results.
- Requirements Life Cycle Management: describes the tasks used to manage and maintain requirements and design information from inception to retirement.
- Strategy Analysis: describes the tasks used to identify the business need, address that need, and align the change strategy within the enterprise.
- Requirements Analysis and Design Definition: describes the tasks used to organize requirements, specify and model requirements and designs, validate and verify information, identify solution options, and estimate the potential value that could be realized.
- Solution Evaluation: describes the tasks used to assess the performance of and value delivered by a solution and to recommend improvements on increasing value.

BABOK knowledge areas organisation by tasks allows easy linking to Business Analysis competences what approach can be used in the intended DS-BoK.

### **3.5 Data Management Body of Knowledge (DM-BoK) by DAMAI**

The Data Management Association International (DAMAI) has been founded in 1988 in US with the aim: (i) to provide a non-profit, vendor-independent association where data professionals can go for help and assistance; (ii) to provide the best practice resources such as the DM-BoK and DM Dictionary of Terms; (iii) to create a trusted environment for DM professionals to collaborate and communicate.

The DM-BoK version2 “Guide for performing data management” is structured in 11 knowledge areas covering core areas in data management:

- (1) Data Governance,
- (2) Data Architecture,
- (3) Data Modelling and Design,
- (4) Data Storage and Operations,
- (5) Data Security,
- (6) Data Integration and Interoperability,
- (7) Documents and Content,
- (8) Reference and Master Data,
- (9) Data Warehousing and Business Intelligence,
- (10) Metadata, and
- (11) Data Quality.

Each KA has section topics that logically group activities and is described by a context diagram. There is also an additional Data Management section containing topics that describe the knowledge requirements for data management professionals. Each context diagram includes: Definition, Goals, Process, Inputs, Supplier roles, Responsible, Stakeholder, Tools, Deliverables, and Metrics (See Appendix A).

When using DM-BoK for defining Data Management knowledge area for DS-BoK (DSDM) it needs to be extended with the recent data modelling technologies and Big Data management platforms that address generic Big Data properties such as Volume, Veracity, Velocity. New data security and privacy protections need to be addressed as well (see CSA Top 10 Big Security challenges [14]).

### **3.6 Project Management Professional Body of Knowledge (PM-BoK)**

The PM-BoK is maintained by the Project Management Institute (PMI) the provides research and education services to Project Managers through publications, networking-opportunities in local chapters, hosting conferences and training seminars, and providing accreditation in project management. PMI, exploit volunteers and sponsorships to expand project management's body of knowledge through research projects, symposiums and surveys, and shares it through publications, research conferences and working sessions. The “A Guide to the Project Management Body of Knowledge” (PM-BoK), has been recognized by the American National Standards Institute (ANSI) and in 2012 ISO adapted the project management processes from the PMBOK Guide 4th edition (see Appendix A).

The PMI-BoK defines five Process Groups related to project management:

- Initiating - Processes to define and authorize a project or project phase
- Planning - Processes to define the project scope, objectives and steps to achieve the required results.
- Executing - Processes to complete the work documented within the Project Management Plan.
- Monitoring and Controlling - Processes to track and review the project progress and performance. This group contains the Change Management.
- Closing - Processes to formalize the project or phase closure.

The nine Knowledge Areas are linked to the Process Groups:

- Project Integration Management - Processes to integrate various parts of the Project Management.
- Project Scope Management - Processes to ensure that all of the work required is completed for a successful Project and manages additional "scope creep".
- Project Time Management - Processes to ensure the project is completed in a timely manner.
- Project Cost Management - Processes to manage the planning, estimation, budgeting and management of costs for the duration of the project.
- Project Quality Management - Processes to plan, manage and control the quality and to provide assurance the quality standards are met.
- Project Human Resource Management - Processes to plan, acquire, develop and manage the project team.
- Project Communications Management - Processes to plan, manage, control, distribute and final disposal of project documentation and communication.
- Project Risk Management - Processes to identify, analyse and management of project risks.
- Project Procurement Management - Processes to manage the purchase or acquisition of products and service, or result to complete the project.
- Project Stakeholder Management – Process to identify stakeholders, determine their requirements, expectations and influence

Each Process Group contains processes within some or all of the Knowledge Areas. Each of the 42 processes has Inputs, Tools and Techniques, and Outputs. (It is not the scope of this analysis enter into the details of each process).

## 4 Data Science Body of Knowledge (DS-BoK) definition

The presented DS-BoK definition is based on overview and analysis of existing bodies of knowledge that are relevant to the Data Science and required to fulfil the identified in CF-DS competences and skills. This is also enriched by analysis of the practice in academic and professional training courses development by universities and professional training organisations.

The DS-BoK can be used as a basis for defining Data Science related curricula, courses, instructional methods, educational/course materials, and necessary practices for university post and undergraduate programs and professional training courses. The DS-BoK is also intended to be used for defining certification programs and certification exam questions. While CF-DS (comprising of competences, skills and knowledge) can be used for defining job profiles (and correspondingly content of job advertisements) the DS-BoK can provide a basis for interview questions and evaluation of the candidate's knowledge and related skills, as well as for professional certification exam and training.

### 4.1 General Approach and Structure of DS-BoK

The DS-BoK contains the following Knowledge Area groups (KAG) that follows the competence groups defined in CF-DS [1]:

- KAG1-DSDA: Data Analytics group including Data Analytics methods, Machine Learning, statistical methods, and data visualisation
- KAG2-DSENG: Data Science Engineering group including software engineering, database and Big Data technologies
- KAG3-DSDM: *Data Management group including data curation, preservation and data modeling*
- KAG4-DSRMP: *Research Methods and Project Management*
- KAG5-DSBA: Business Analytics (also strongly based on KAG1-DSDA)
- KAG\*-DSDK: Placeholder for the Data Science Domain Knowledge groups to include domain specific knowledge

The subject domain related knowledge group (scientific or business) KAG\*-DSDK is recognized as essential for practical work of Data Scientist what in fact means not professional work in a specific subject domain but understanding the domain related concepts, models and organisation (refer to CF-DS section 4.8 [1]) and corresponding data analysis methods and models. These knowledge areas will be a subject for future development in tight cooperation with subject domain specialists.

It is also anticipated that due to complexity of Data Science domain, the DS-BoK will require wide spectrum of background knowledge, first of all in mathematics, statistics, logics and reasoning as well as general computing, and cloud computing in particular. Similar to the ACM CS2013 curricula approach, background knowledge can be required as an entry condition or must be studied as elective courses.

The proposed DS-BoK re-uses where possible existing BoK's taking necessary KA and KU definitions and combining them into defined above DS-BoK knowledge area groups. The following BoK's were used and/or mapped to the selected DS-BoK knowledge groups:

- ACM Computer Science CS-BoK [7, 8]
- Business Analysis BABOK [10]
- Software Engineering SWEBOK [11]
- Data Management DMBOK by DAMA [12],
- Project Management PM-BoK [13],
- Classification Computer Science (CCS2012) [6] for Computer Science related knowledge areas.

### 4.2 Data Science Body of Knowledge Areas and Knowledge Units

Table 1 provides consolidated view of the identified Knowledge Areas in the Data Science Body of Knowledge. The table contains detailed definition of the KAG1-DSDA, KAG2-DSENG, KAG3-DSDM groups that are well supported by existing BoK's and academic materials. General suggestions are provided for KAG4-DSRMP, KAG5-

DSBA groups that corresponds to newly identified competences and knowledge areas and require additional study of existing practices and contribution from experts in corresponding scientific or business domains.

The KAG1-DSDA Data Analytics knowledge area group is key and distinguishing KAG for DS-BoK. It includes different methods and algorithms, primarily statistical, machine learning and data mining, to enable data processing, modelling, analysis and inspection with the goal of discovering useful information, providing insight and recommendations, and supporting decision-making. The following are commonly defined the Data Science Analytics Knowledge Areas:

- KA01.01 (DSDA.01/SMA) Statistical methods, including Descriptive statistics, exploratory data analysis (EDA) focused on discovering new features in the data, and confirmatory data analysis (CDA) dealing with validating formulated hypotheses;
- KA01.02 (DSDA.02/ML) Machine learning and related methods for information search, image recognition, decision support, classification;
- KA01.03 (DSDA.03/DM) *Data mining* is a particular data analysis technique that focuses on modelling and knowledge discovery for predictive rather than purely descriptive purposes;
- KA01.04 (DSDA.04/TDM) Text analytics applies statistical, linguistic, and structural techniques to extract and classify information from textual sources, a species of unstructured data;
- KA01.05 (DSDA.05/PA) Predictive analytics focuses on application of statistical models for predictive forecasting or classification.
- KA01.06 (DSDA.06/BA) Business Analytics and Business Intelligence covers data analysis that relies heavily on aggregation and different data sources and focusing on business information;
- KA01.07 (DSDA.07/MSO) Computational modelling, simulation and optimisation

The KAG2-DSENG group includes selected KAs from ACM CS-BoK and SWEBOK and extends them with new technologies and engineering technologies and paradigm such as cloud based, agile technologies and DevOps that are promoted as continuous deployment and improvement paradigm and allow organisation implement agile business and operational models.

The KAG3-DSDM group includes most of KAs from DM-BoK however extended it with KAs related to RDA recommendations, community data management models (Open Access, Open Data, etc.) and general Data Lifecycle Management that is used as a central concept in many data management related education and training courses.

Table 2 provides detailed definition of DS-BoK Knowledge Areas and Knowledge Units. Knowledge Units (KU) corresponding to suggested KAs are defined from different sources: existing BoK, CCS2012, and from practices in designing academic curricula and corresponding courses by universities and professional training organisations<sup>5</sup>.

The presented DS-BoK high level content is not exhaustive at this stage and will undergo further development based on feedback from MC-DS implementation.

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<sup>5</sup> KAs and KUs defined in such a way are not exclusive (as mentioned above) but have a benefit of being close to academic practice and allowing easier and faster implementation.

Table 1. DS-BoK Knowledge Area Groups and corresponding Knowledge Areas

KA Groups	Suggested DS Knowledge Areas (KA)	Knowledge Areas from existing BoK and CCS2012 scientific subject groups
KAG1-DSDA: Data Science Analytics	KA01.01 (DSDA.01/SMDA) Statistical methods for data analysis KA01.02 (DSDA.02/ML) Machine Learning KA01.03 (DSDA.03/DM) Data Mining KA01.04 (DSDA.04/TDM) Text Data Mining KA01.05 (DSDA.05/PA) Predictive Analytics KA01.06 (DSDA.06/MODSIM) Computational modelling, simulation and optimisation	There is no formal BoK defined for Data Analytics.  Data Science Analytics related scientific subjects from CCS2012: CCS2012: Computing methodologies CCS2012: Mathematics of computing CCS2012: Computing methodologies
KAG2-DSENG: Data Science Engineering	KA02.01 (DSENG.01/BDIT) Big Data Infrastructure and Technologies KA02.02 (DSENG.02/DSIAPP) Infrastructure and platforms for Data Science applications KA02.03 (DSENG.03/CCT) Cloud Computing technologies for Big Data and Data Analytics KA02.04 (DSENG.04/SEC) Data and Applications security KA02.05 (DSENG.05/BDSE) Big Data systems organisation and engineering KA02.06 (DSENG.06/DSAPPD) Data Science (Big Data) applications design KA02.07 (DSENG.07/IS) Information systems (to support data driven decision making)	ACM CS-BoK selected KAs: AL - Algorithms and Complexity AR - Architecture and Organization (including computer architectures and network architectures) CN - Computational Science GV - Graphics and Visualization IM - Information Management PBD - Platform-based Development (new) SE - Software Engineering (can be extended with specific SWEBOOK KAs)  SWEBOOK selected KAs <ul style="list-style-type: none"> <li>• Software requirements</li> <li>• Software design</li> <li>• Software engineering process</li> <li>• Software engineering models and methods</li> <li>• Software quality</li> </ul> Data Science Analytics related scientific subjects from CCS2012: CCS2012: Computer systems organization CCS2012: Information systems CCS2012: Software and its engineering
KAG3-DSDM: Data Management	KA03.01 (DSDM.01/DMORG) General principles and concepts in Data Management and organisation KA03.02 (DSDM.02/DMS) Data management systems KA03.03 (DSDM.03/EDMI) Data Management and Enterprise data infrastructure KA03.04 (DSDM.04/DGOV) Data Governance KA03.05 (DSDM.05/BDSTOR) Big Data storage (large scale)	DM-BoK selected KAs (1) Data Governance, (2) Data Architecture, (3) Data Modelling and Design, (4) Data Storage and Operations, (5) Data Security, (6) Data Integration and Interoperability, (7) Documents and Content, (8) Reference and Master Data, (9) Data Warehousing and Business Intelligence, (10) Metadata, and (11) Data Quality.



KA Groups	Suggested DS Knowledge Areas (KA)	Knowledge Areas from existing BoK and CCS2012 scientific subject groups
	KA03.06 (DSDM.05/DLIB) Digital libraries and archives	Data Science Analytics related scientific subjects from CCS2012: CCS2012: Information systems
KAG4-DSRM: Research Methods and Project Management	KA04.01 (DSRMP.01/RM) Research Methods KA04.01 (DSRMP.02/PM) Project Management	There are no formally defined BoK for research methods  PMI-BoK selected KAs <ul style="list-style-type: none"> <li>• Project Integration Management</li> <li>• Project Scope Management</li> <li>• Project Quality</li> <li>• Project Risk Management</li> </ul>
KAG5-DSBPM: Business Analytics	KA05.01 (DSBA.01/BAF) Business Analytics Foundation KA05.02 (DSBA.02/BAEM) Business Analytics organisation and enterprise management	BABOK selected KAs *) <ul style="list-style-type: none"> <li>• Business Analysis Planning and Monitoring: describes the tasks used to organize and coordinate business analysis efforts.</li> <li>• Requirements Analysis and Design Definition.</li> <li>• Requirements Life Cycle Management (from inception to retirement).</li> <li>• Solution Evaluation and improvements recommendation.</li> </ul>

\*) BABOK KA are more business focused and related to KAG5-DSBA, however its specific topics related to data analysis can be reflected in the KAG1-DSDA

Table 2. Detailed definition of the DS-BoK and suggested Knowledge Units (KU)

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
		KU1.01.01	Probability & Statistics	
		KU1.01.02	Statistical paradigms (regression, time series, dimensionality, clusters)	
KAG1-DSDA: Data Science Analytics	KA01.01 DSDA.01/SMDA Statistical methods for data analysis	KU1.01.03	Probabilistic representations (causal networks, Bayesian analysis, Markov nets)	<b>CCS2012: Mathematics of computing</b> <ul style="list-style-type: none"> <li>Discrete mathematics <ul style="list-style-type: none"> <li>Graph theory</li> <li>Probability and statistics</li> <li>Probabilistic representations</li> <li>Probabilistic inference problems</li> <li>Probabilistic reasoning algorithms</li> <li>Probabilistic algorithms</li> </ul> </li> <li>Statistical paradigms</li> <li>Mathematical software</li> <li>Information theory</li> <li>Mathematical analysis</li> </ul>
		KU1.01.04	Frequentist and Bayesian statistics	
		KU1.01.05	Probabilistic reasoning	
		KU1.01.06	Exploratory and confirmatory data analysis	
		KU1.01.07	Quantitative analytics	
		KU1.01.08	Qualitative Analytics	
		KU1.01.09	Data preparation and preprocessing	
		KU1.01.10	Performance analysis	
		KU1.01.11	Markov models, Markov networks	
		KU1.01.12	Operations research	
		KU1.01.13	Information theory	
		KU1.01.14	Discrete Mathematics and Graph Theory	
		KU1.01.15	Mathematical analysis	
		KU1.01.16	Mathematical software and tools	
KAG1-DSDA: Data Science Analytics	KA01.02 DSDA.02/ML Machine Learning	KU1.02.01	Machine Learning theory and algorithms	<b>CCS2012: Computing methodologies</b> <ul style="list-style-type: none"> <li>Artificial intelligence <ul style="list-style-type: none"> <li>Machine learning</li> <li>Learning paradigms <ul style="list-style-type: none"> <li>Supervised learning</li> <li>Unsupervised learning</li> <li>Reinforcement learning</li> <li>Multi-task learning</li> </ul> </li> </ul> </li> </ul>
		KU1.02.02	Supervised Machine Learning	
		KU1.02.03	Unsupervised Machine Learning	
		KU1.02.04	Reinforced learning	
		KU1.02.05	Classification methods	
		KU1.02.06	Design and Analysis of Algorithms	
		KU1.02.07	Game Theory & Mechanism design	
		KU1.02.08	Artificial Intelligence	
		KU1.01.02	Statistical paradigms (regression, time series, dimensionality, clusters)	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
		KU1.01.03	Probabilistic representations (causal networks, Bayesian analysis, Markov nets)	<ul style="list-style-type: none"> <li>Machine learning approaches <ul style="list-style-type: none"> <li>Machine learning algorithms</li> </ul> </li> </ul>
		KU1.01.04	Frequentist and Bayesian statistics	<b>CCS2012: Theory of computation</b> <ul style="list-style-type: none"> <li>Design and analysis of algorithms <ul style="list-style-type: none"> <li>Data structures design and analysis</li> </ul> </li> <li>Theory and algorithms for application domains <ul style="list-style-type: none"> <li>Machine learning theory</li> <li>Algorithmic game theory and mechanism design</li> </ul> </li> <li>Semantics and reasoning</li> </ul>
		KU1.01.05	Probabilistic reasoning	
		KU1.01.08	Performance analysis	
KAG1-DSDA: Data Science Analytics	KA01.03 DSDA.03/DM Data Mining	KU1.01.08	Performance analysis	<b>CCS2012: Theory of computation</b> <ul style="list-style-type: none"> <li>Design and analysis of algorithms <ul style="list-style-type: none"> <li>Data structures design and analysis</li> </ul> </li> <li>Theory and algorithms for application domains <ul style="list-style-type: none"> <li>Machine learning theory</li> <li>Algorithmic game theory and mechanism design</li> </ul> </li> <li>Semantics and reasoning</li> </ul>
		KU1.02.01	Machine Learning theory and algorithms	
		KU1.02.02	Supervised Machine Learning	
		KU1.02.03	Unsupervised Machine Learning	
		KU1.02.04	Reinforced learning	
		KU1.02.05	Classification methods	
		KU1.03.01	Data mining and knowledge discovery	
		KU1.03.02	Knowledge Representation and Reasoning	
		KU1.03.03	CRISP-DM and data mining stages	
		KU1.03.04	Anomaly Detection	
		KU1.03.05	Time series analysis	
		KU1.03.06	Feature selection, Apriori algorithm	
		KU1.03.07	Graph data analytics	
KAG1-DSDA: Data Science Analytics	KA01.04 DSDA.04/TDM Text Data Mining	KU1.04.01	Text analytics including statistical, linguistic, and structural techniques to analyse structured and unstructured data	<b>CCS2012: Computing methodologies</b> <ul style="list-style-type: none"> <li>Artificial intelligence <ul style="list-style-type: none"> <li>Natural language processing</li> <li>Knowledge representation and reasoning</li> </ul> </li> </ul>
		KU1.04.02	Data mining and text analytics	
		KU1.04.03	Natural Language Processing	
		KU1.04.04	Predictive Models for Text	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
		KU1.04.05	Retrieval and Clustering of Documents	<ul style="list-style-type: none"> <li>○ Search methodologies</li> </ul>
		KU1.04.06	Information Extraction	
		KU1.04.07	Sentiments analysis	
KAG1-DSDA: Data Science Analytics	KA01.05 DSDA.05/PA Predictive Analytics	KU1.05.01	Predictive modeling and analytics	
		KU1.05.02	Inferential and predictive statistics	
		KU1.05.03	Machine Learning for predictive analytics	
		KU1.05.04	Regression and Multi Analysis	
		KU1.05.05	Generalised linear models	
		KU1.05.06	Time series analysis and forecasting	
		KU1.05.07	Deploying and refining predictive models	
KAG1-DSDA: Data Science Analytics	KA01.06 DSDA.06/MODSIM Computational modelling, simulation and optimisation	KU1.06.01	Modelling and simulation theory and techniques (general and domain oriented)	<b>CCS2012: Computing methodologies</b> <ul style="list-style-type: none"> <li>● Modeling and simulation <ul style="list-style-type: none"> <li>○ Model development and analysis</li> <li>○ Simulation theory</li> <li>○ Simulation types and techniques</li> <li>○ Simulation support systems</li> </ul> </li> </ul>
		KU1.06.02	Operations research and optimisation	
		KU1.06.03	Large scale modelling and simulation systems	
		KU1.06.04	Network optimisation	
		KU1.06.05	Risk simulation and queueing	
KAG2-DSENG: Data Science Engineering	KA02.01 DSENG.01/BDI Big Data Infrastructure and Technologies	KU2.01.01	Computer systems organisation for Big Data applications, CAP, BASE and ACID theorems	<b>CCS2012: Computer systems organization</b> <ul style="list-style-type: none"> <li>● Architectures <ul style="list-style-type: none"> <li>○ Parallel architectures</li> <li>○ Distributed architectures</li> </ul> </li> <li>● Networks *) <ul style="list-style-type: none"> <li>○ Network Architectures</li> <li>○ Network Services</li> <li>○ Cloud Computing</li> </ul> </li> </ul>
		KU2.01.02	Parallel and Distributed Computer Architecture	
		KU2.01.03	High Performance and Cloud Computing	
		KU2.01.04	Clouds and scalable computing	
		KU2.01.05	Cloud based Big Data platforms and services	
		KU2.01.06	Big Data (large scale) storage and filesystems (HDFS, Ceph, etc)	
		KU2.01.07	NoSQL databases	
		KU2.01.08	Computer networks for high-performance computing and Big Data infrastructure	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
		KU2.01.09	Computer networks: architectures and protocols	
		KU2.01.10	Big Data Infrastructure management and operation	
KAG2- DSENG: Data Science Engineering	KA02.02 DSENG.02/DSIAPP Infrastructure and platforms for Data Science applications	KU2.02.01	Big Data Infrastructure: services and components, including data storage infrastructure	<ul style="list-style-type: none"> <li>Proposed new KA for DS-BoK</li> <li>Infrastructure and platforms for Data Science applications group:</li> <li>CCENG - Cloud Computing Engineering (infrastructure and services design, management and operation)</li> <li>CCAS - Cloud based applications and services development and deployment</li> <li>BDA – Big Data Analytics platforms (including cloud based)</li> <li>BDI - Big Data Infrastructure services and platforms, including data storage infrastructure</li> </ul>
		KU2.02.02	Big Data analytics platforms and tools (including Hadoop, Spark, and cloud based Big Data services)	
		KU2.02.03	Large scale cloud based storage and data management	
		KU2.02.04	Cloud based applications and services operation and management	
		KU2.02.05	Big Data and cloud based systems design and development	
		KU2.02.06	Data processing models (batch, streaming, parallel)	
		KU2.02.07	Enterprise information systems	
		KU2.02.08	Data security and protection	<b>CCS2012: Information systems</b> <ul style="list-style-type: none"> <li>Information storage systems</li> <li>Information systems applications</li> </ul>
KAG2- DSENG: Data Science Engineering	KA02.03 DSENG.03/CCT Cloud Computing technologies for Big Data and Data Analytics	KU2.03.01	Cloud Computing architecture and services	<b>DSDA Extension group for CCS201</b> <b>Theory of computation</b> <ul style="list-style-type: none"> <li>DSA Extension point: Algorithms for Big Data computation</li> </ul> <b>Mathematics of computing</b> <ul style="list-style-type: none"> <li>DSA Extension point: Mathematical</li> </ul>
		KU2.03.02	Cloud Computing Engineering (infrastructure and services design, management and operation)	
		KU2.03.03	Cloud based applications and services operation and management	
KAG2- DSENG: Data	KA02.04 DSENG.04/SEC	KU2.04.01	Infrastructure, applications and data security	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
Science Engineering	Data and Applications security	KU2.04.02	Data encryption and key management, blockchain based technologies	software for Big Data computation <b>Computing methodologies</b> <ul style="list-style-type: none"> <li>• DSA Extension point: New DSA computing</li> </ul> <b>Information systems</b> <ul style="list-style-type: none"> <li>• DSA Extension point: Big Data systems (e.g. cloud based)</li> </ul> <b>Information systems applications</b> <ul style="list-style-type: none"> <li>• DSA Extension point: Big Data applications</li> </ul> DSA Extension point: Domain specific Data applications
		KU2.04.03	Access Control and Identity Management	
		KU2.04.04	Security services management, including compliance and certification	
		KU2.04.05	Data anonymisation	
		KU2.04.06	Data privacy	
KAG2-DSENG: Data Science Engineering	KA02.05 DSENG.05/BDSE Big Data systems organisation and engineering	KU2.05.01	Big Data systems organisation and design	<b>CCS2012: Software and its engineering</b> <ul style="list-style-type: none"> <li>• Software organization and properties               <ul style="list-style-type: none"> <li>○ Software system structures</li> </ul> </li> <li>• Software architectures               <ul style="list-style-type: none"> <li>○ Software system models</li> <li>○ Distributed systems organizing principles                   <ul style="list-style-type: none"> <li>▪ Cloud computing</li> <li>▪ Grid computing</li> </ul> </li> </ul> </li> <li>• Software notations and tools               <ul style="list-style-type: none"> <li>○ General programming languages</li> <li>○ Software creation and management</li> </ul> </li> </ul>
		KU2.05.02	Big Data algorithms for large scale data processing	
		KU2.05.03	Big Data Analytics	
		KU2.05.04	Big Data analytics platforms and tools (including Hadoop, Spark, and cloud based Big Data services)	
		KU2.05.05	Big Data algorithms for data ingest, pre-processing, and visualisation	
		KU2.05.06	Big Data systems for application domains	
		KU2.05.07	Big Data software (systems) architectures	
		KU2.05.08	Requirements engineering and software systems development	
		KU2.05.09	Large and ultra-large scale software systems organisation	
		KU2.05.10	DevOps and cloud enabled applications development	
		KU2.05.11	Big Data Infrastructure management and operation	
KAG2-DSENG: Data Science Engineering	KA02.06 DSENG.06/DSAPPD	KU2.06.01	Data analytics, data handling software requirements and design	<b>SWEBOK selected KAs</b> <ul style="list-style-type: none"> <li>• Software requirements</li> <li>• Software design</li> </ul>
		KU2.06.02	Applications engineering management	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
	Data Science (Big Data) applications design	KU2.06.03	Software engineering models and methods	<ul style="list-style-type: none"> <li>• Software construction</li> <li>• Software testing</li> <li>• Software maintenance</li> <li>• Software configuration management</li> <li>• Software engineering management</li> <li>• Software engineering process</li> <li>• Software engineering models and methods</li> <li>• Software quality</li> <li>• Agile development technologies</li> <li>• Methods, platforms and tools</li> <li>• DevOps and continuous deployment and improvement paradigm</li> </ul>
		KU2.06.04	Software quality assurance	
		KU2.06.05	Programming languages for Big Data analytics: R, python, Pig, Hive, others	
		KU2.06.06	Models and languages for complex interlinked data presentation and visualisation	
		KU2.06.07	Agile development methods, platforms and tools	
		KU2.06.08	DevOps and continuous deployment and improvement paradigm	
KAG2- DSENG: Data Science Engineering	KA02.07 DSENG.07/IS Information systems (to support data driven decision making)	KU2.07.01	Decision Analysis and Decision Support Systems	<b>CCS2012: Information systems</b> <ul style="list-style-type: none"> <li>• Information systems applications <ul style="list-style-type: none"> <li>○ Decision support systems <ul style="list-style-type: none"> <li>▪ Data warehouses</li> <li>▪ Expert systems</li> <li>▪ Data analytics</li> <li>▪ Online analytical processing</li> </ul> </li> <li>○ Multimedia information systems</li> <li>○ Data mining</li> </ul> </li> </ul>
		KU2.07.02	Predictive analytics and predictive forecasting	
		KU2.07.03	Data Analysis and statistics	
		KU2.07.04	Data warehousing and Data Mining	
		KU2.07.05	Data Mining	
		KU2.07.06	Multimedia information systems	
		KU2.07.07	Enterprise information systems	
		KU2.07.08	Collaborative and social computing systems and tools	
				<b>CCS2012: Information systems</b> <ul style="list-style-type: none"> <li>• Information systems applications <ul style="list-style-type: none"> <li>○ Enterprise information systems</li> <li>○ Collaborative and social computing systems and tools</li> </ul> </li> </ul>
	KA03.01	KU3.01.01	Data type registries, PID, metadata	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
KAG3-DSDM: Data Management	DSDM.01/DMORG General principles and concepts in Data Management and organisation	KU3.01.02	Data Lifecycle Management	<b>Proposed new KA for DS-BoK</b> General Data Management KA's <ul style="list-style-type: none"> <li>Data Lifecycle Management</li> <li>Data archives/storage compliance and certification</li> </ul>
		KU3.01.03	Data infrastructure and Data Factories	
		KU3.01.04	Research data infrastructure, Open Science, Open Data, Open Access, ORCID	
		KU3.01.05	Data infrastructure compliance and certification	New KAs to support RDA recommendations and community data management models (Open Access, Open Data, etc) <ul style="list-style-type: none"> <li>Data type registries, PIDs</li> <li>Data infrastructure and Data Factories</li> <li>New KAs to follow RDA and ERA community developments</li> </ul>
		KU3.01.06	Ethical principle and data privacy	
		KU3.01.07	FAIR (Findable, Accessible, Interoperable) principles in Data Management	
KAG3-DSDM: Data Management	KA03.02 DSDM.02/DMS Data management systems	KU3.02.01	Data architectures (OLAP, OLTP, ETL)	<b>CCS2012: Information systems</b> <ul style="list-style-type: none"> <li>Data management systems <ul style="list-style-type: none"> <li>Database design and models</li> <li>Data structures</li> <li>Database management system engines</li> <li>Query languages</li> <li>Database administration</li> <li>Middleware for databases</li> <li>Information integration</li> </ul> </li> <li>CCS2012: Theory of computation <ul style="list-style-type: none"> <li>Database theory</li> </ul> </li> </ul>
		KU3.02.02	Data Modelling, Databases and Database Management Systems	
		KU3.02.03	Data structures	
		KU3.02.04	Data Models and Query Languages	
		KU3.02.05	Database design and models	
		KU3.02.06	Database administration	
		KU3.02.07	Data warehouses	
		KU3.02.08	Middleware for databases	
KAG3-DSDM: Data Management	KA03.03 DSDM.03/EDMI Data Management and Enterprise data infrastructure	KU3.03.01	Data management, including Reference and Master Data	<b>DM-BoK selected KAs</b> (1) Data Governance, (2) Data Architecture, (3) Data Modelling and Design,
		KU3.03.02	Data Warehousing and Business Intelligence	
		KU3.03.03	Data storage and operations	



Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
		KU3.03.04	Data archives/storage compliance and certification	(4) Data Storage and Operations, (5) Data Security, (6) Data Integration and Interoperability, (7) Documents and Content, (8) Reference and Master Data, (9) Data Warehousing and Business Intelligence, (10) Metadata, and (11) Data Quality.
		KU3.03.05	Metadata, linked data, provenance	
		KU3.03.06	Data infrastructure, data registries and data factories	
		KU3.03.07	Data security and protection	
		KU3.03.08	Data backup	
		KU3.03.09	Data anonymisation	
		KU3.03.10	Data Privacy	
KAG3-DSDM: Data Management	KA03.04 DSDM.04/DGOV Data Governance	KU3.04.01	Data governance, data quality, data Integration and Interoperability	DM-BoK (as above)
		KU3.04.02	Data Management Planning	
		KU3.04.03	Data Management Policy	
		KU3.04.04	Data interoperability	
		KU3.04.05	Data curation	
		KU3.04.06	Data provenance	
		KU3.04.07	Responsible data use, data privacy, ethical principles, IPR, legal issues	
KAG3-DSDM: Data Management	KA03.05 DSDM.05/BDSTOR Big Data storage (large scale)	KU3.05.01	Big Data storage infrastructure and operations	New DSENG Knowledge area: Big Data Storage <ul style="list-style-type: none"> <li>• Distributed file systems</li> <li>• Data Lakes</li> <li>• Data Factories</li> </ul>
		KU3.05.02	Storage architectures, distributed files systems (HDFS, Ceph, Lustre, Gluster, etc)	
		KU3.05.03	Data storage redundancy and backup	
		KU3.05.04	Data factories, data pipelines	
		KU3.05.05	Cloud based storage, Data Lakes	
KAG3-DSDM: Data Management	KA03.06 DSDM.05/DLIB Digital libraries and archives	KU3.06.01	Digital libraries and archives organisation	CCS2012: Information systems <ul style="list-style-type: none"> <li>• Information systems applications <ul style="list-style-type: none"> <li>○ Digital libraries and archives</li> </ul> </li> </ul>
		KU3.06.02	Information Retrieval	
		KU3.06.03	Data curation and provenance	
		KU3.06.04	Search Engines technologies	
KAG4-DSRMP: Research Methods and Project Management	KA04.01 DSRMP.01/RM Research Methods	KU4.01.01	Research methodology, paradigms and research cycle	Proposed new KA for DS-BoK for DSRM related competences: <ul style="list-style-type: none"> <li>• Research methodology, research cycle (e.g. 4 steps model)</li> </ul>
		KU4.01.02	Modelling and experiment planning	
		KU4.01.03	Data selection and quality evaluation	
		KU4.01.04	Data lifecycle	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
		KU4.01.05	Use cases analysis: research infrastructures and projects	Hypothesis – Research Methods – Artefact – Validation) <ul style="list-style-type: none"> <li>• Modelling and experiment planning</li> <li>• Data selection and quality evaluation</li> <li>• Use cases analysis: research infrastructures and projects</li> </ul>
		KU4.01.06	Research data management plan and ethical issues	
KAG4-DSRMP: Research Methods and Project Management	KA04.01 DSRMP.02/PM Project Management	KU4.02.01	Project Integration Management	<b>PMI-BoK selected KAs</b> <ul style="list-style-type: none"> <li>• Project Integration Management</li> <li>• Project Scope Management</li> <li>• Project Quality</li> <li>• Project Risk Management</li> </ul>
		KU4.02.02	Project Scope Management	
		KU4.02.03	Project Quality	
		KU4.02.04	Project Risk Management	
KAG5-DSBPM: Business Analytics	KA05.01 DSBA.01/BAF Business Analytics Foundation	KU5.01.01	Business Analytics and Business Intelligence: Data, Models (statistical) and Decisions	<b>BABOK selected KAs</b> <ul style="list-style-type: none"> <li>• Business Analysis Planning and Monitoring: describes the tasks used to organize and coordinate business analysis efforts.</li> <li>• Requirements Analysis and Design Definition.</li> <li>• Requirements Life Cycle Management (from inception to retirement).</li> <li>• Solution Evaluation and improvements recommendation.</li> </ul>
		KU5.01.02	Data driven Customer Relations Management (CRP), User Experience (UX) requirements and design	
		KU5.01.03	Operations Analytics	
		KU5.01.04	Business Process Optimization	
		KU5.01.05	Data Warehouses technologies, data integration and analytics	
		KU5.01.06	Data driven marketing technologies	
		KU5.01.07	Business Analytics Capstone	
		KU5.01.08	Econometrics methods and application for Business Analytics	
		KU5.01.09	Cognitive technologies for Business Analytics	
KAG6-DSBA: Business Analytics	KA05.02 DSBA.02/BAEM Business Analytics organisation and enterprise management	KU5.02.01	Business processes and operations	<b>Proposed new KA/KU for DS-BoK</b> <ul style="list-style-type: none"> <li>• General Business processes and operations KAs</li> <li>• Business processes and operations</li> </ul>
		KU5.02.02	Project scope and risk management	
		KU5.02.03	Business Analysis Planning and Monitoring	
		KU5.02.04	Requirements Analysis and Design Definition	

Knowledge Area Groups (KAG)	Knowledge Areas (KA)	Knowledge Unit (KU)	Suggested Knowledge Units (KU)	Mapping to CCS2012 and existing BoKs (DMBOK, BABOK, PMI-BoK, SWEBOK, ACM BoK)
		KU5.02.05	Requirements Life Cycle Management (from inception to retirement)	<ul style="list-style-type: none"> <li>Agile Data Driven methodologies, processes and enterprises</li> <li>Use cases analysis: business and industry</li> </ul>
		KU5.02.06	Solution Evaluation and improvements recommendation	
		KU5.02.07	Agile Data Driven methodologies, processes and enterprises	
		KU5.02.08	Use cases analysis: business and industry	

## 5 Conclusion and further developments

The presented work on defining the DS-BoK and other foundational components of the whole EDISON Data Science Framework have been done with wide consultation and engagement of different stakeholders, primarily from research community and Research Infrastructures, but also involving industry experts via standardisation bodies, professional communities and directly via the project network.

### 5.1 Summary of the recent development

The presented Data Science Body of Knowledge defines necessary knowledge areas and knowledge units required by the Data Science competences defined in the CF-DS document [1].

DS-BoK includes the following Knowledge Area groups (KAG):

- KAG1-DSDA: Data Analytics group including Data Analytics methods, Machine Learning, statistical methods, and data visualisation
- KAG2-DSENG: Data Science Engineering group including software engineering, database and Big Data technologies
- KAG3-DSDM: *Data Management group including data curation, preservation and data modeling*
- KAG4-DSRMP: *Research Methods and Project Management*
- KAG5-DSBA: Business Analytics (also strongly based on KAG1-DSDA)
- KAG\*-DSDK: Placeholder for the Data Science Domain Knowledge groups to include domain specific knowledge

### 5.2 Further developments to formalize CF-DS and DS-BoK

It is anticipated that the presented ongoing development will require practical validation by experts and communities of practice that will include the following specific tasks and activities:

- Continue validating and improving the currently proposed knowledge areas and knowledge units by involving experts in the related knowledge areas, beneficially also engaging with the specific professional communities such as IEEE, ACM, DAMA, IIBA, etc.
- Formalise the taxonomy definition of the Data Science related knowledge areas and scientific disciplines based on ACM CCS (2012), provide suggestions for new knowledge areas and classifications classes.
- Collect feedback from the known pilot implementation of the EDSF and DS-BoK by the champion universities and wider community of practitioners to provide further update to the DS-BoK.

Initial validation of the proposed DS-BoK has been done during the EDISON project lifetime by actively involving project partners and champion universities, engaging with the community of practice via workshops, seminars and active outreach activity, and soliciting feedback and contribution from the academic and professional community, including experts' interviews. Numerous of feedbacks and comments have been collected since the last EDSF Release 2 published in July 2017.

To ensure successful acceptance of the proposed EDSF and its core components, essential role belong to the standardisation in the related technology and educational domains. This work has been done in the EDISON project. Necessary contacts with the European and international standardisation bodies and professional organisations have been established and currently maintained.

Future support for EDSF and DS-BoK in particular will be provided in the framework of the community shared EDISON Initiative that is committed to support the EDSF implementation and regular updates like current Release 3 that summarised the community experience and continuous feedback.

## 6 References

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- [3] Data Science Model Curriculum [online] <https://github.com/EDISONcommunity/EDSF/tree/master/data-science-model-curriculum>
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- [16] European Skills, Competences, Qualifications and Occupations (ESCO) [online] <https://ec.europa.eu/esco/portal/home>

## Acronyms

Acronym	Explanation
ACM	Association for Computer Machinery
BABOK	Business Analysis Body of Knowledge
CCS	Classification Computer Science by ACM
CF-DS	Data Science Competence Framework
CODATA	International Council for Science: Committee on Data for Science and Technology
CS	Computer Science
DM-BoK	Data Management Body of Knowledge by DAMAI
DS-BoK	Data Science Body of Knowledge
EDSA	European Data Science Academy
EOEE	EDISON Online E-Learning Environment
ETM-DS	Data Science Education and Training Model
EUDAT	<a href="http://eudat.eu/what-eudat">http://eudat.eu/what-eudat</a>
EGI	European Grid Initiative
ELG	EDISON Liaison Group
EOSC	European Open Science Cloud
ERA	European Research Area
ESCO	European Skills, Competences, Qualifications and Occupations
EUA	European Association for Data Science
HPCS	High Performance Computing and Simulation Conference
ICT	Information and Communication Technologies
IEEE	Institute of Electrical and Electronics Engineers
IPR	Intellectual Property Rights
LERU	League of European Research Universities
LIBER	Association of European Research Libraries
MC-DS	Data Science Model Curriculum
NIST	National Institute of Standards and Technologies of USA
PID	Persistent Identifier
PM-BoK	Project Management Body of Knowledge
PRACE	Partnership for Advanced Computing in Europe
RDA	Research Data Alliance
SWEBOK	Software Engineering Body of Knowledge

## Appendix A. Overview of Bodies of Knowledge relevant to Data Science

This section provides detailed information about existing Bodies of Knowledge relevant to the Data Science Body of Knowledge definition which are linked to or mapped to the current DS-BoK.

### A.1. ICT Professional Body of knowledge

Character	Explanation
Name of the Profession	ICT professional
Reference Community	(potentially) all ICT Professional
Leadership	Capgemini Consulting and Ernst & Young for the European Commission, Directorate General Internal Market, Industry, Entrepreneurship and SMEs
Organisation structure	N/A
Partners	N/A
Ethical Code	N/A
Estimated #members	N/A
Link to BoK	<a href="http://www.ictbok.eu/images/EU_Foundationa_ICTBOK_final.pdf">http://www.ictbok.eu/images/EU_Foundationa_ICTBOK_final.pdf</a>
Year/Edition	2015/1st
Structure of BoK	There are 12 Knowledge Areas: <ol style="list-style-type: none"> <li><b>1.</b> ICT Strategy &amp; Governance</li> <li><b>2.</b> Business and Market of ICT</li> <li><b>3.</b> Project Management</li> <li><b>4.</b> Security Management</li> <li><b>5.</b> Quality Management</li> <li><b>6.</b> Architecture</li> <li><b>7.</b> Data and Information Management</li> <li><b>8.</b> Network and Systems Integration</li> <li><b>9.</b> Software Design and Development</li> <li><b>10.</b> Human Computer Interaction</li> <li><b>11.</b> Testing</li> <li><b>12.</b> Operations and Service Management</li> </ol>
Proposed use of BoK	Each Knowledge Area is defined by; <ul style="list-style-type: none"> <li>• List of items required as foundational knowledge necessary under this Knowledge Area;</li> <li>• List of references to the e-Competence Framework (dimension 4: knowledge);</li> <li>• List of possible job profiles that require having an understanding of the Knowledge Area;</li> <li>• List of examples of specific Bodies of Knowledge, certification and training possibilities</li> <li>• Education providers: as a source of inspiration for curricula design and development;</li> <li>• Professional Associations: to promote the Body of Knowledge to their members, ICT professionals;</li> <li>• HR Department and Managers within industry with a need to understand the range of knowledge and the entry level required by ICT professionals in order to improve recruiting and people development processes (together with skills and competencies).</li> </ul>
Certification promoted	N/A

## A.2. Data Management Professional Body of knowledge

Character	Explanation
Name of the Profession	Data Management Professional
Reference Community Leadership	Mainly US Data managers, professionals and scholars. Relevant chapters in UK and Australia. DAMAI a Volunteer US-based organization governed by an Executive Board of Directors. Directors are voted in for a 2 year term of office and may stand for re-election
Organisation structure	The members adhere through the nearest local chapter and through that (autonomous organisations affiliated with the central associations) participate to the life of the community
Partners	US-based organisation of medium relevance that provide educational resources (Dataversity, DEBtech, IRM UK, Technics Publications) or instruments and tools (VoltDB)
Ethical Code	Yes (available for members <a href="https://www.dama.org/content/chapter-kit-behind-login">https://www.dama.org/content/chapter-kit-behind-login</a> )
Estimated #members	Conferences are attended by a thousand people, 16 Chapters worldwide. No references about number of subscriptions
Link to BoK	BoK Framework <ul style="list-style-type: none"> <li>• <a href="http://www.dama.org/sites/default/files/download/DAMA-DMBOK2-Framework-V2-20140317-FINAL.pdf">http://www.dama.org/sites/default/files/download/DAMA-DMBOK2-Framework-V2-20140317-FINAL.pdf</a></li> </ul> DAMA International Guide to Data Management Body of Knowledge (on purchase) <ul style="list-style-type: none"> <li>• <a href="https://technicspub.com/dmbok/">https://technicspub.com/dmbok/</a></li> </ul> Other resources DAMA International Dictionary of Data Management Terms (on purchase) <ul style="list-style-type: none"> <li>• <a href="https://technicspub.com/dmbok/">https://technicspub.com/dmbok/</a></li> </ul>
Edition/version	2012/v.2
Structure of BoK	The document is structured in 11 knowledge areas covering core areas in the DAMA - DMBOK2 Guide for performing data management. The 11 Data Management Knowledge Areas are: <ol style="list-style-type: none"> <li>1. <b>Data Governance</b> – planning, oversight, and control over management of data and the use of data and data-related resources. Governance covers ‘processes’, not ‘things’, hence the common term for Data Management Governance is Data Governance.</li> <li>2. <b>Data Architecture</b> – the overall structure of data and data-related resources as an integral part of the enterprise architecture</li> <li>3. <b>Data Modelling &amp; Design</b> – analysis, design, building, testing, and maintenance (was Data Development in the DAMA - DMBOK 1<sup>st</sup> edition)</li> <li>4. <b>Data Storage &amp; Operations</b> – structured physical data assets storage deployment and management (was Data Operations in the DAMA-DMBOK 1<sup>st</sup> edition)</li> <li>5. <b>Data Security</b> – ensuring privacy, confidentiality and appropriate access</li> <li>6. <b>Data Integration &amp; Interoperability</b> – acquisition, extraction, transformation, movement, delivery, replication, federation, virtualization and operational support (a Knowledge Area new in DMBOK2)</li> <li>7. <b>Documents &amp; Content</b> – storing, protecting, indexing, and enabling access to data found in unstructured sources (electronic files and physical records), and making this data available for integration and interoperability with structured (database) data.</li> </ol>



8. **Reference & Master Data** – Managing shared data to reduce redundancy and ensure better data quality through standardized definition and use of data values.
9. **Data Warehousing & Business Intelligence** – managing analytical data processing and enabling access to decision support data for reporting and analysis
10. **Metadata** – collecting, categorizing, maintaining, integrating, controlling, managing, and delivering metadata
11. **Data Quality** – defining, monitoring, maintaining data integrity, and improving data quality

Each KA has section topics that logically group activities and it is described by a context diagram. There is also an additional Data Management section containing topics that describe the knowledge requirements for data management professionals.

Each context diagram includes:

- *Definition*: a concise description of the Knowledge Area.
- *Goals*: the desired outcomes of the Knowledge Area within this Topic.
- *Process*: the list of discrete activities and sub-activities to be performed, with activity group indicators.
- *Inputs*: what documents or raw materials are directly necessary for a Process to initiate or continue
- *Supplier roles*: roles and/or teams that supply the inputs to the process.
- *Responsible roles*: roles and/or teams that perform the process.
- *Stakeholder roles*: roles and/or teams informed or consulted on the process execution.
- *Tools*: technology types used by the process to perform the function.
- *Deliverables*: what is directly produced by the processes
- *Consumer roles*: roles and/or teams that expect and receive the Deliverables.
- *Metrics*: Measurements That quantify the success of Processes based on the Goals

Proposed use of BoK

- Informing a diverse audience about the nature and importance of data management.
- Helping build consensus within the data management community.
- Helping data stewards, data owners, and data professionals understand their responsibilities.
- Providing the basis for assessments of data management effectiveness and maturity.
- Guiding efforts to implement and improve data management knowledge areas.
- Educating students, new hires, practitioners and executives on data management knowledge areas
- Guiding the development and delivery of data management curriculum content for higher education.
- Suggesting areas of further research in the field of data management.
- Helping data management professionals prepare for Certified Data Management Professional (CDMP) data exams.
- Assisting organizations in defining their enterprise data strategy.

Certified Data Management Professional (CDMP) in four levels:

- Associate (<https://www.dama.org/content/cdmp-associate>),
- Practitioner (<https://www.dama.org/content/cdmp-practitioner>),
- Master (<https://www.dama.org/content/cdmp-master>),
- Fellow (<https://www.dama.org/content/cdmp-fellow>)

Certification promoted

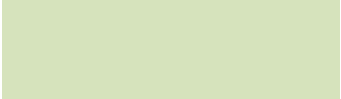
Cost per exam: vary depending on the examination (from \$220 of Associate till the 1560 for Master). Fellow is an assigned through nomination by peers and Chapter.

Requirements: member of local chapter, sign/adhere to Ethical code/ proven experiences verifiable on the CV and contributions to the Association at various level

### A.3. Project Management Professional Body of knowledge

Character	Explanation
Name of the Profession	Project Management Professional
Reference Community	Industry-centred worldwide Project Managers
Leadership	Project Management Institute – <a href="http://www.pmi.org">www.pmi.org</a>
	PMI is a worldwide not-for-profit professional membership association for the project, program and portfolio management profession. Founded in 1969, PMI delivers advocacy, collaboration, education and research to its members.
Organisation structure	PMI is governed by a 15-member volunteer Board of Directors. Each year PMI members elect five directors to three-year terms. Three directors elected by others on the Board serve one-year terms as officers. Day-to-day PMI operations are guided by the Executive Management Group and professional staff at the Global Operations Centre located near Philadelphia.
	Each member adheres through the nearest local chapter and through that (autonomous organisations affiliated with the central associations) participate to the life of the community
Partners	No specific partnership but some 1600 Registered Education Providers (R.E.P.s) and about 100 certified courses worldwide ( <a href="http://www.pmi.org/learning/professional-development/global-accreditation-center.aspx">http://www.pmi.org/learning/professional-development/global-accreditation-center.aspx</a> )
Ethical Code	Yes ( <a href="http://www.pmi.org/About-Us/Ethics/Code-of-Ethics.aspx#">http://www.pmi.org/About-Us/Ethics/Code-of-Ethics.aspx#</a> )
Estimated #members	700.000 in 195 countries (source <a href="http://www.pmi.org">www.pmi.org</a> ) [Estimated some 2,9 acting PM worldwide and some 1,5 million PM posts till 2020]
Link to BoK	<a href="http://www.pmi.org/PMBOK-Guide-and-Standards/pmbok-guide.aspx">http://www.pmi.org/PMBOK-Guide-and-Standards/pmbok-guide.aspx</a> (on purchase - \$46,17)
	other resources
	<ul style="list-style-type: none"> <li>• Lexicon of PM terms (<a href="http://www.pmi.org/PMBOK-Guide-and-Standards/PMI-lexicon.aspx">http://www.pmi.org/PMBOK-Guide-and-Standards/PMI-lexicon.aspx</a> - free for members)</li> <li>• PMBoK in other 11 languages (Arabian, Italian, Korean, Russian, Hindi, Japanese, Portuguese, Spanish, German, French, Chinese);</li> <li>• <b>Software Extension to the PMBOK</b> Guide Fifth Edition (This standard, developed by PMI jointly with IEEE Computer Society, provides guidance on the management of software development projects, and bridges the gap between the traditional, predictive approach described in the PMBOK® Guide and iterative approaches such as agile more commonly used in software development) (on purchase – \$37,07)</li> </ul>
	External sites:
	<a href="http://www.projectmanagement.com/Practices/PMI-Standards/">http://www.projectmanagement.com/Practices/PMI-Standards/</a>
Year/Edition	2014/5 <sup>th</sup> edition
Structure of BoK	The Five Process Groups
	<i>Initiating</i> - Processes to define and authorize a project or project phase

	<p><i>Planning</i> - Processes to define the project scope, objectives and steps to achieve the required results.</p> <p><i>Executing</i> - Processes to complete the work documented within the Project Management Plan.</p> <p><i>Monitoring and Controlling</i> - Processes to track and review the project progress and performance. This group contains the Change Management.</p> <p><i>Closing</i> - Processes to formalize the project or phase closure.</p> <p>The Nine Knowledge Areas</p> <p><i>Project Integration Management</i> - Processes to integrate various parts of the Project Management.</p> <p><i>Project Scope Management</i> - Processes to ensure that all of the work required is completed for a successful Project and manages additional "scope creep".</p> <p><i>Project Time Management</i> - Processes to ensure the project is completed in a timely manner.</p> <p><i>Project Cost Management</i> - Processes to manage the planning, estimation, budgeting and management of costs for the duration of the project.</p> <p><i>Project Quality Management</i> - Processes to plan, manage and control the quality and to provide assurance the quality standards are met.</p> <p><i>Project Human Resource Management</i> - Processes to plan, acquire, develop and manage the project team.</p> <p><i>Project Communications Management</i> - Processes to plan, manage, control, distribute and final disposal of project documentation and communication.</p> <p><i>Project Risk Management</i> - Processes to identify, analyse and management of project risks.</p> <p><i>Project Procurement Management</i> - Processes to manage the purchase or acquisition of products and service, or result to complete the project.</p> <p>Each Process Group contains processes within some or all of the Knowledge Areas. Each of the 42 processes has Inputs, Tools &amp; Techniques and Outputs. (It is not the scope of this analysis enter into the details of each process).</p>
Proposed use of BoK	<p>It provides project managers with the fundamental practices needed to achieve organizational results and excellence in the practice of project management. It's a competence framework to support the PM practices. It's used also as "one of the books" to pass the examination.</p>
Certification promoted	<p>Several certification other than the basic about Project Management Professional in correspondence of specific roles that the PM may adopt in the carrier or depending on the type of project  <a href="http://www.pmi.org/certification.aspx">http://www.pmi.org/certification.aspx</a>:  CAPM – Certified Associate Project Management  PMP – Project Management Professional  PgMP – Program Management Professional  PfMP – Portfolio Management Professional  PMI–PBA – PMI-Professional Business Analyst  PMI-ACP – PMI Agile Certified Professional  PMI-RMP – PMI Risk Management Professional  PMI-SP – Scheduling Professional</p> <p>Cost: it may vary from the \$225 of CAPM till the \$900 for PgMP and PfMP of non-Members;</p>



*Requirements:* general Education (Secondary school or Degree) + Experience on the field of certification + specific Education on the field of certification.

## Appendix B. Subset of ACM/IEEE CCS2012 for Data Science (as defined in DS-BoK Release 1)

This Appendix provides historical information about subset of the ACM/IEEE CCS2012 taxonomy used in the DS-BoK Release 1. This information is provided for those who build their Data Science curriculum definition on the previous DS-BoK version. The new DS-BoK Release 3 version has the whole set of the generically defined knowledge areas and knowledge units that can be partly mapped to CCS2012 but primarily based on the knowledge topics defined in CF-DS document.

The defined below subset of ACM CCS (2012) classification can provide a basis for its future extension with a new classification group related to Data Science and individual disciplines that are missing in the current ACM/IEEE classification.

### B.1. ACM Classification Computer Science (2012) structure and Data Science related Knowledge Areas

The 2012 ACM Computing Classification System (CCS) [6] has been developed as a poly-hierarchical ontology that can be utilized in semantic web applications. It replaces the traditional 1998 version of the ACM Computing Classification System (CCS), which has served as the de facto standard classification system for the computing field for many years (also been more human readable). The ACM CCS (2012) is being integrated into the search capabilities and visual topic displays of the ACM Digital Library. It relies on a semantic vocabulary as the single source of categories and concepts that reflect the state of the art of the computing discipline and is receptive to structural change as it evolves in the future. ACM provides a tool within the visual display format to facilitate the application of 2012 CCS categories to forthcoming papers and a process to ensure that the CCS stays current and relevant.

However, at the moment none of Data Science, Big Data or Data Intensive Science technologies are reflected in the ACM classification. The following is an extraction of possible classification facets from ACM CCS (2012) related to Data Science what reflects multi-subject areas nature of Data Science:

As an example, the Cloud Computing that is also a new technology and closely related to Big Data technologies, currently is classified in ACM CCS (2012) into 3 groups:

**Networks** :: Network services :: Cloud Computing

**Computer systems organization** :: Architectures :: Distributed architectures :: Cloud Computing

**Software and its engineering** :: Software organization and properties :: Software Systems Structures :: Distributed systems organizing principles :: Cloud Computing

Taxonomy is required to consistently present information about scientific disciplines and knowledge areas related to Data Science. Taxonomy is important component to link such components as Data Science competences and knowledge areas, Body of Knowledge, and corresponding academic disciplines. From practical point of view, taxonomy includes vocabulary of names (or keywords) and hierarchy of their relations.

The presented here initial taxonomy of Data Science disciplines and knowledge areas is based on the 2012 ACM Computing Classification System (ACM CCS (2012)). Refer to initial analysis of ACM CCS (2012) classification and subset of data related disciplines in the DS-BoK Release 1. Table B.1 below includes ACM CCS (2012) subsets/subtrees that contain scientific disciplines that are related to Data Science Knowledge Area groups as defined in DS-BoK Release 1, which are compatible with the DS-BoK Release 2 and later:

- KAG1-DSDA: Data Analytics group including Machine Learning, statistical methods, and Business Analytics
- KAG2-DENG: Data Science Engineering group including Software Engineering and infrastructure engineering
- KAG3-DSDM: Data Management group including data curation, preservation and data infrastructure

Two other groups KAG4-DSRMP: Research Methods and Project Management and KAG5-DSBPM: Business Process Management cannot be mapped to ACM CCS (2012) and their taxonomy is defined based on other bodies of knowledge. It is important to notice that ACM CCS (2012) provides a top level classification entry

“Applied computing” that can be used as an extension point for domain related knowledge area group KAG6-DSDK.

The following approach was used when constructing the proposed taxonomy:

- ACM CCS (2012) provides almost full coverage of Data Science related knowledge areas or disciplines related to KAG1, KAG2, and KAG3. The following top level classification groups are used:
- Theory of computation
- Mathematics of computing
- Computing methodologies
- Information systems
- Computer systems organization
- Software and its engineering
- Each of KAGs includes subsets from few ACM CCS (2012) classification groups to cover theoretical, technology, engineering and technical management aspects.
- Extension points are suggested for possible future extensions of related KAGs together with their hierarchies.
- KAG3-DSDM: Data Management group is extended with new concepts and technologies developed by Research Data Alliance community and documented in community best practices.

**Table B.1 Data Science classification based on ACM Classification (2012)**

DS-BoK Knowledge Groups *)	ACM (2012) Classification facets related to Data Science	
Data Science Analytics (DSDA)	Theory of computation	Design and analysis of algorithms Data structures design and analysis Theory and algorithms for application domains Machine learning theory Algorithmic game theory and mechanism design Database theory Semantics and reasoning
Data Science Analytics (DSDA)	Mathematics of computing	Discrete mathematics Graph theory Probability and statistics Probabilistic representations Probabilistic inference problems Probabilistic reasoning algorithms Probabilistic algorithms Statistical paradigms Mathematical software Information theory Mathematical analysis
Data Science Analytics (DSDA)	Computing methodologies	Artificial intelligence Natural language processing Knowledge representation and reasoning Search methodologies Machine learning Learning paradigms Supervised learning Unsupervised learning Reinforcement learning Multi-task learning Machine learning approaches Machine learning algorithms
Data Science Analytics (DSDA)	Information systems	Information systems applications Decision support systems Data warehouses Expert systems Data analytics Online analytical processing Multimedia information systems

DS-BoK Knowledge Groups *)	ACM (2012) Classification facets related to Data Science
	Data mining
Data Science Analytics (DSDA)	Theory of computation DSA Extension point: Algorithms for Big Data computation
EXTENSION POINT	Mathematics of computing DSA Extension point: Mathematical software for Big Data computation
	Computing methodologies DSA Extension point: New DSA computing
	Information systems DSA Extension point: Big Data systems (e.g. cloud based)
	Information systems applications DSA Extension point: Big Data applications
	DSA Extension point: Domain specific Data applications
Data Science Data Management (DSDM)	Information systems Data management systems Database design and models Data structures Database management system engines Query languages Database administration Middleware for databases Information integration
Data Science Data Management (DSDM)	Information systems Information systems applications Digital libraries and archives Information retrieval Document representation Retrieval models and ranking Search engine architectures and scalability Specialized information retrieval
Data Science Data Management (DSDM)	Information systems Data management systems Data types and structures description Metadata standards Persistent identifiers (PID) Data types registries
EXTENSION POINT	
Data Science Engineering (DSE)	Computer systems organization Architectures Parallel architectures Distributed architectures
Data Science Engineering (DSENG)	Networks **) Network Architectures Network Services Cloud Computing
Data Science Engineering (DSENG)	Software and its engineering Software organization and properties Software system structures Software architectures Software system models Ultra-large-scale systems Distributed systems organizing principles Cloud computing Grid computing Abstraction, modeling and modularity Real-time systems software
	Software notations and tools General programming languages Software creation and management
Data Science Engineering (DSENG)	Computing methodologies Modeling and simulation Model development and analysis Simulation theory Simulation types and techniques Simulation support systems
Data Science Engineering (DSENG)	Information systems Information storage systems Information systems applications Enterprise information systems

DS-BoK Knowledge Groups *)	ACM (2012) Classification facets related to Data Science	
		Collaborative and social computing systems and tools
Data Science Engineering (DSENG)	Software and its engineering	Software organization and properties
		DSE Extension point: Big Data applications design
EXTENSION POINT		Data Analytics programming languages
	Information systems	
		DSE Extension point: Big Data and cloud based systems design
		Information systems applications
		DSA Extension point: Big Data applications
		DSA Extension point: Domain specific Data applications
DS Domain Knowledge (DSDK)	Applied computing	
		Physical sciences and engineering
		Life and medical sciences
EXTENSION POINT		Law, social and behavioral sciences
		Computer forensics
		Arts and humanities
		Computers in other domains
		Operations research
		Education
		Document management and text processing

\*) All Acronyms for classification groups and DS-BoK Knowledge Area Groups are brought in accordance to CF-DS-competence groups

\*\*) Due to important role of the Internet and networking technologies, basic knowledge about networks are required. However, as a technology domain, Networks knowledge area group should be considered as a domain specific knowledge area in the general Data Science competences and knowledge definition.