Towards a Capabilities Taxonomy for Prognostics and Health Management

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ABSTRACT

Within the mandate of the PHM Society there is a strong emphasis to advance the domain of prognostics and health management (PHM). However, the practitioners within this multi-disciplinary domain use or could apply diverse science and engineering skills. This communication proposes the development of a classification or taxonomy for the skills needed for the PHM field. A structure and process is defined to ensure application to real needs by employers, practitioners and training developers. Preliminary results of the development of several sub-domains within the PHM field are reported based on a workshop at the PHM 2012 conference. Steps for a way forward are proposed as well methods for interested parties to participate are suggested.

1. BACKGROUND

Prognostics and Health Management (PHM) is a diverse, multi-disciplinary domain with rapidly evolving capability needs. Initial PHM education and training from many discipline entry points must be complemented by specialized and professional development over a career.

The community has identified that benchmarks are needed for career planners, employers and training developers to facilitate transitions between mastery levels.

The community’s stakeholders in academia, industry and government require a stream of qualified practitioners with lifelong professional development.

Aligned with this scenario, the PHM Society has objectives to:

- promote the development, growth, and recognition of prognostics and health management (PHM) as an engineering discipline;
- support PHM education by developing standard teaching curricula in the field; and
- establishing, developing, or adopting standards, methods, and metrics in PHM;

To accomplish these objectives the board of the Society has approved activities in this direction through a committee on Education and Professional Development.

2. PROPOSAL

Through the PHM Society the goal is to compile a PHM Taxonomy or classification that maps:

| Skill/capability areas e.g. signal processing, statistics, control systems, [as rows] |
| Competency levels: Entry, Working or Mastery for each [as columns] |

Employers: A job description could be readily prepared to include a capabilities list from various areas with desired mastery levels. Evaluation schemes could reference mastery levels to be demonstrated or developed. Professional development transitions could be defined and matched to courses or in-house assignments.

Practitioners: To plan education and professional development progressions and understand skills and capabilities required.

Training and professional course developers: To identify niche areas and descriptors for likely pre-requisites available and new competencies to be acquired.

3. COMPETENCY DEFINITIONS

Competency definitions are required for this use of such taxonomy. Pedagogical references provide a basis for the selection of a working set [1, 2].
The progression of complexity is typical within the hierarchies used. For example [3], a creative thinking skill aims to respond to challenges with innovative solutions, products or services by questioning conventional means, using intuition, experimentation and fresh perspectives. Five levels of competency with descriptors are provided [3]:

**Level 1: Understands how to solve problems**
Uses common sense and knowledge to identify underlying issues and to solve problems.
Uses appropriate problem-solving techniques.

**Level 2: Identifies existing solutions**
Reviews existing options, concepts and approaches, and identifies one(s) that will work in the situation at hand.
Stands back from a problem and observes patterns and interrelationships in data to see where problems or discrepancies arise.
Recognizes and assesses several likely causes or ways of interpreting available information.
Recognizes when a new approach is needed to solve a problem.
Solves complex problems through application of existing theories or explanations.

**Level 3: Modifies existing solutions**
Questions traditional solutions and uses unconventional methods to find solutions.
Thinks about problems from a new perspective.
Applies ideas from other disciplines or fields of research to solve problems.

**Level 4: Creates new solutions/concepts**
Thinks several steps ahead in deciding on best course of action (anticipates likely outcomes).
Creates, assesses and applies new concepts, theories, approaches and/or solutions.
Solves complex or inter-related problems through developing new theories, explanations or applications.

**Level 5: Impacts a field of science/technology**
Develops new theories and applications with revolutionizing or wide-ranging impacts.

Alternatively, a technical skill can also be categorized by breadth of application [4]:

1. Engineering and technical contribution at the subsystem level is required.

2. The conversion of concepts to subsystems and systems, major system design and/or technical leader in multiple projects

3. A developer of engineering concepts, major system design, and/or technical leader in multiple programs. A principal contributor in systems design, systems engineering, concept development, and project reports.

For this PHM taxonomy we have decided to use three levels that incorporate important aspects of these two above approaches:

1. Entry Level: Understands, selects, interprets and applies basic concepts and known methods. May work at the subsystem level.

2. Working Level: Analyses and solves complex problems by combining or extending existing methods. Integrates and validates at the system level.

3. Mastery Level: Evaluates, innovates, synthesizes and validates new methods through unique, often multi-disciplinary insights.

Application of skills may include analysis, design, build/implement and test for equipment, hardware and software.

**4. PHM SKILLS AND CAPABILITIES**
Compiling a list of possible skills for PHM practitioners is challenging because the field is multi-disciplinary. A generic PHM taxonomy has been proposed by Jennions [5]. He identifies some key skills related to business, systems design, architecture, analytics, technologies, applications and support. In addition, work in PHM taxonomies by SAE HM-1 is expected to provide the following insights because of the broad membership base.

This work aims to extend these taxonomies to meet the stakeholder needs defined above with a comprehensive list of skills. Firstly, we propose to subdivide skills and capabilities as follows:

1. Domain: major category of a technical skill or competency

2. Sub-domain: constituent sub category that could be associated with a stream of graduate courses

3. Specialty: subject that could constitute a specific course

While it is acknowledged that there are overlaps to be defined, a working list of key PHM domains and sub-domains (with some sample specialties) is proposed:

1. System physical modeling
   a. Fluid mechanics- aerodynamics, hydraulics/hydrodynamics
   b. Electrical/Electronics
   c. Mechanical
   d. Structural
2. Data Modeling
   a. Parametric
   b. Non-parametric
   c. Hybrid
3. Analytics
   a. Data pre-processing
   b. Feature extraction
   c. Feature selection
   d. Classification- methods, metrics
   e. Regression- methods, metrics
   f. Optimization- methods, metrics
   g. Model Fusion
   h. Anomaly Detection
   i. Fault Isolation- observability, coverage
   j. Prognostics- specialized methods, metrics (e.g. latency)
   k. Data Fusion by data types
   l. Special Issues with time series data
   m. Special Issues with nominal data types
   n. Reasoners- meta-classifiers, Bayesian, fuzzy logic
   Note: Diagnostics is considered to comprise e to i and n
4. Test and Experimental (Design and conduct)
   a. Data acquisition- steady state, targeted, transient, dynamic
   b. Inspection/evaluation- NDI/E
   c. Uncertainty analysis
   d. Sensor
   e. Data reduction
   f. Data transmission
   g. Fault implantation
5. Software Systems
   a. Architecture- standards
   b. Real time system
   c. User interfaces
   d. Software system integration (up to enterprise integration)
   e. Data compression
6. Hardware Systems
   a. Off board- standards
   b. On board- standards
   c. Sensors- design, specification, integration
7. Life Cycle Analysis
   a. Root cause analysis
   b. Fault Tree Analysis
   c. Functional Hazard Analysis
   d. Fault accommodation
   e. Trade studies
   f. Reliability
   g. Availability
   h. Maintainability
   i. FMECA- FM, E, C
8. Verification and Validation
   a. Methods
   b. Maturation
9. Human Factors
   a. Needs analysis- standards
   b. Usability - standards
10. Systems Engineering
    a. Usage Monitoring
    b. Health Management- State Awareness, Diagnostics, Prognostics, Decision Support
    c. Autonomous systems
11. Cost Benefit Analysis
    a. Needs analysis
    b. Risk Analysis
    c. Metrics, uncertainty/confidence and evaluation
    d. Business case
    e. Support Service/Performance Based Logistics approaches
12. Certification
    a. Standards
    b. Safety Status Analysis
    c. Risk management
    d. Post certification management
13. Standards

5. SAMPLE CAPABILITIES-COMPETENCY MAPPING

Here we take a practitioner skills/capability viewpoint as opposed to the IVHM system components view. A sample taxonomy entry is provided in the following table to illustrate some descriptors for a selected specialty within the Analytics domain and diagnostics sub-domain.

| Specialty          | Entry Level descriptors | Working Level descriptors | Mastery Level descriptors |
|--------------------|-------------------------|---------------------------|---------------------------|
| Methods            | Apply existing single and multi-disciplinary methods | Assess shortcomings in existing methods-adapt/hybridize methods to suit | Develop new methods from novel physics or mathematical insights |
| Metrics            | Apply appropriate existing metrics | Adapt metrics to complex system evaluation | Devise and approve system level metrics |

Table 1: Sample Taxonomy Entry
6. DEVELOPMENT OF TAXONOMY

The PHM Society Education and Professional development Committee sponsored a workshop at the PHM 2012 annual conference to workshop the concept described above. Three significant domains were selected, each to have a broad based group examine the sub-domain list and also to draft competency descriptors. While these drafts are neither complete nor final, it was felt that the developing a ‘strawman’ version would be helpful to the Society.

6.1 Domain 1- Analytics

The working group at the PHM 2012 conference agreed to proceed with the sub-domains in section 4 above. However, they considered the prognostics sub-domain separate and were not able to address it in the time available. They proposed working versions of the competency descriptions for most of the sub-domains in that list and added some specific specialties within some sub-domains. For a number of the specialties/analysis tools they chose the same generic descriptors. Annex 1 provides the results. In general, they proposed application of existing tools at the entry level, adaptation at the working level and customization or new methods at the mastery level.

6.2 Domain 2- Test and Experiment Design

The working group at the conference added additional sub-domains: integration, fault injection/insertion, data validation, data reduction and data management. They chose not to add specialties, in the limited time available. The descriptors addressed a number of diverse skills and capabilities across the hardware/software/sensor scope of this domain. Details are provided in Annex 2.

6.3 Domain 3- Cost Benefit Analysis

The group who discussed the important Cost Benefit Analysis domain proposed adding sub-domains for asset management, maintenance and the effect of prognostics management, and business versus customer perspective. It was also suggested that the metrics, uncertainty/confidence and evaluation sub-domain might be considered as specialties within the risk analysis sub-domain. Details are provided in Annex 3.

7 CONCLUSIONS AND WAY FORWARD

The need for a broadly applicable PHM taxonomy has received a preliminary validation through a limited workshop process. The three classes of users were confirmed. The general form and a working set of definitions have been developed and reviewed. Draft taxonomies for three PHM domains have been proposed for further development through either workshops or specialists. The appropriate number and level of detail for the specialties is yet to be determined.

The PHM Society Education and Professional Development Committee is coordinating actions to:

1. Prepare and circulate a Working Model of a PHM Capabilities Taxonomy- this communication document
2. Conduct Conference Workshops covering evolving issues and the taxonomy approach- planned for PHM 2013
3. Develop the inputs for the details for this taxonomy from subject matter experts
4. Compile sources for entry level skills
5. Compile courses available for transitions across competency levels from existing materials and programs in various organizations
6. Identify gaps in current post-secondary and graduate continuing education materials and opportunities

Linkages with the SAE HM-1 committee will ensure that this work is complementary. In the longer term, the PHM Society would work with appropriate organizations to develop needed materials and opportunities. In this direction, the PHM Society is establishing a comprehensive set of technical co-sponsorships with major organizations.

Interested parties are invited and encouraged to contribute by contacting one of the authors or participating in the on-line forum at www.phmsociety.org/forum/577.

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BIOGRAPHIES

Jeff Bird is currently a consultant with TECnos Consulting Services, Ottawa, Canada. His present avocations include advancing the art, science and business of prognostics and health management in diverse fields. Specifically, he leads PHM Society board initiatives in Education and Professional Development as well as Standards. He recently completed one career spanning 30 years as a Research Officer at the Gas Turbine Laboratory of the National Research Council Canada. His published research there included gas turbine dynamics and performance, health monitoring and management, adverse environments, and uncertainty. Previously he worked as an Operational Research officer in the Department of National Defence where he enjoyed contributing to airlift and search and rescue planning. He studied at the University of Toronto (Engineering Science - Aerospace) and at Carleton University (Mechanical, Aerospace and Systems).

Nancy Madge is a partner at TECnos Consulting Services. She specializes in curriculum development for adult learning and training in industrial and professional settings. Over some 28 years, she has developed user needs definitions, course designs and materials for participants and instructors across diverse applications such as telephony, calculus, tax law, computer systems and process operation. Her Bachelor’s qualifications are in Music Education at the University of Western Ontario complemented by Master’s work in curriculum design at Brock University. She completed integrated arts and education coursework towards a doctorate at the University of Toronto’s Ontario Institute for Studies in Education.

Dr. Karl Reichard is a Research Associate at the Applied Research Laboratory at The Pennsylvania State University and Deputy Department Head of the Advanced Sensors and Controls Department in the Multisensor Processing Division. He has more than 15 years of experience in the development of advanced sensors, measurement systems, and signal processing algorithms. An Assistant Professor of Acoustics at Penn State and Head of the Condition-Based Maintenance Department at the University's Applied Research Laboratory, Dr. Reichard leads advanced research and development efforts in embedded systems, electro-optics, intelligent acoustic and vibration sensors, and signal processing and classification algorithms for active noise and vibration control, manufacturing machinery monitoring, and surveillance systems. Prior to joining Penn State ARL in 1991, he was employed by the U.S. Army Aberdeen Proving Grounds and Virginia Polytechnic Institute and State University, his alma mater. Dr. Reichard has published more than 25 papers in refereed journals, conference publications, and technical reports. Dr. Reichard serves as Associate Editor of the International Journal on Prognostics and Health Management.
### Annex 1: Draft Taxonomy for Analytics Domain

| Sub-domain                | Specialty                        | Entry Level descriptors                                                                 | Working Level descriptors                                                                 | Mastery Level descriptors                                                                                   |
|---------------------------|----------------------------------|-----------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|
| Diagnostics               | Methods                          | Apply existing single and multi-disciplinary methods                                      | Assess shortcomings in existing methods- adapt/hybridize methods to suit Other             | Develop new methods from novel physics or mathematical insights                                              |
|                           |                                  | Other                                                                                    | Other                                                                                    |                                                                                                               |
| Metrics                   |                                  | Apply appropriate existing metrics                                                       | Adapt metrics to complex system evaluation                                                 | Devise and bring into acceptance system level metrics                                                         |
| Data pre-processing       | De-noising / outlier detection   | Ability to implement and apply algorithms.                                                | Ability to decide which algorithms to apply, choose parameters for analysis, modify existing algorithms | Develop new techniques and approaches based on mathematical insight                                          |
|                           |                                  | Ability to understand algorithms                                                         |                                                                                           |                                                                                                               |
|                           | Transformation                   | Understand and use database                                                              | Ability to choose appropriate database design from existing designs and match tools to PHM requirements | Customization of database, database design, optimization                                                     |
|                           | Special issues with nominal data types |                                                                                       |                                                                                           | Ability to recognize and apply appropriate processing techniques to accommodate differences in data types |
| Feature extraction        |                                  |                                                                                         |                                                                                           |                                                                                                               |
| Feature selection         | Physics / Engineering Approaches  | Works with SME to identify techniques and applies/implements                             | Understands how to decompose problem/system and identifies appropriate SME                  | Develop engineering or physical models and new techniques                                                   |
| Statistical Approaches    |                                  | Ability to implement and apply algorithms.                                                | Ability to decide which algorithms to apply, choose parameters for analysis, modify existing algorithms | Develop new techniques and approaches based on mathematical insight. Ability to work cross domain with Machine learning or Engineering/physical approaches |
|                           |                                  | Ability to understand algorithms                                                         |                                                                                           |                                                                                                               |
| Machine learning          |                                  | Ability to implement and apply algorithms.                                                | Ability to decide which algorithms to apply, choose parameters for analysis, modify existing algorithms | Develop new techniques and approaches based on mathematical insight. Ability to work cross domain with statistical approaches or Engineering/physical approaches |
| Classification            | Cluster analysis / unsupervised  | Ability to implement and apply algorithms.                                                | Ability to decide which algorithms to apply, choose                                        | Develop new techniques and approaches based on                                                                 |
|                           |                                  | Ability to understand algorithms                                                         | parameters for analysis, modify existing algorithms                                       |                                                                                                               |
|                           |                                  |                                                                                         |                                                                                           |                                                                                                               |
| Sub-domain            | Specialty          | Entry Level descriptors                                                                 | Working Level descriptors                                                                 | Mastery Level descriptors                                                                 |
|----------------------|--------------------|----------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| learning             |                    | apply algorithms.                                                                      | parameters for analysis, modify existing algorithms. Knows multiple techniques             | mathematical insight. Increased breadth of knowledge                                       |
| Supervised learning  | Ability to implement and apply algorithms. Ability to understand algorithms | Ability to decide which algorithms to apply, choose parameters for analysis, modify existing algorithms. Knows multiple techniques | Develop new techniques and approaches based on mathematical insight. Increased breadth of knowledge |
| Statistical approaches| Ability to implement and apply algorithms. Ability to understand algorithms | Ability to decide which algorithms to apply, choose parameters for analysis, modify existing algorithms. Knows multiple techniques | Develop new techniques and approaches based on mathematical insight. Increased breadth of knowledge |
| Metrics              | Apply appropriate existing metrics | Adapt metrics to complex system evaluation                                              | Devise and bring into acceptance system level metrics                                       |
| Regression           | Statistical techniques | Ability to implement and apply algorithms. Ability to understand algorithms             | Ability to decide which algorithms to apply, choose parameters for analysis, modify existing algorithms. Knows multiple techniques Ability to understand and apply hybrid techniques | Develop new techniques and approaches based on mathematical insight. Increased breadth of knowledge |
| Machine learning     | Ability to implement and apply algorithms. Ability to understand algorithms | Ability to decide which algorithms to apply, choose parameters for analysis, modify existing algorithms. Knows multiple techniques Ability to understand and apply hybrid techniques | Develop new techniques and approaches based on mathematical insight. Increased breadth of knowledge |
| Optimization         | Gradient-based     | TBD                                                                                    | TBD                                                                                       | TBD                                                                                       |
| Evolutionary         | TBD                | TBD                                                                                    | TBD                                                                                       | TBD                                                                                       |
| Operations Research  | TBD                | TBD                                                                                    | TBD                                                                                       |                                              |
| Model Fusion         | Applies existing algorithms. Understanding of basic voting techniques | Ability to decide on which algorithms to employ, understanding of machine learning and statistical techniques | Development of new techniques                                                             |
| Fault detection and isolation (includes anomaly detection) | Ability to implement and apply algorithms. Ability to understand algorithms | Ability to decide which algorithms to apply, choose parameters for analysis, modify existing algorithms. Knows multiple techniques | Develop new techniques and approaches based on mathematical insight. Increased breadth of knowledge |
| Data fusion          | Data level         | TBD                                                                                    |                                              |                                              |
| Sub-domain | Specialty | Entry Level descriptors | Working Level descriptors | Mastery Level descriptors |
|------------|-----------|-------------------------|--------------------------|--------------------------|
| Feature level | TBD | Ability to implement and apply algorithms. | Ability to decide which algorithms to apply, choose parameters for analysis, modify existing algorithms. Knows multiple techniques. Ability to understand and apply hybrid techniques | Develop new techniques and approaches based on mathematical insight. Increased breadth of knowledge |
| Decision level | TBD | Ability to implement and apply algorithms. | Ability to decide which algorithms to apply, choose parameters for analysis, modify existing algorithms. Knows multiple techniques. Ability to understand and apply hybrid techniques | |
| Special issues with time-series data | TBD | Ability to implement and apply algorithms. | Ability to decide which algorithms to apply, choose parameters for analysis, modify existing algorithms. Knows multiple techniques. Ability to understand and apply hybrid techniques | |
| Reasoners | Bayesian | Ability to implement and apply algorithms. Ability to understand algorithms | Ability to decide which algorithms to apply, choose parameters for analysis, modify existing algorithms. Knows multiple techniques. Ability to understand and apply hybrid techniques | |
| | Expert systems | Ability to implement and apply algorithms. Ability to understand algorithms | Ability to decide which algorithms to apply, choose parameters for analysis, modify existing algorithms. Knows multiple techniques. Ability to understand and apply hybrid techniques | Develop new techniques and approaches based on mathematical insight. Increased breadth of knowledge |
| | Fuzzy logic | Ability to implement and apply algorithms Ability to understand algorithms | Ability to decide which algorithms to apply, choose parameters for analysis, modify existing algorithms. Knows multiple techniques. Ability to understand and apply hybrid techniques | Develop new techniques and approaches based on mathematical insight. Increased breadth of knowledge |
| | Meta-classifiers | Ability to implement and apply algorithms. Ability to understand algorithms | Ability to decide which algorithms to apply, choose parameters for analysis, modify existing algorithms. Knows multiple techniques. Ability to understand and apply hybrid techniques | Develop new techniques and approaches based on mathematical insight. Increased breadth of knowledge |
| | Fault isolation | Ability to implement and apply algorithms. Ability to understand algorithms | Ability to decide which algorithms to apply, choose parameters for analysis, modify existing algorithms. Knows multiple techniques. Ability to understand and apply hybrid techniques | Develop new techniques and approaches based on mathematical insight. Increased breadth of knowledge |
| Prognostics | Statistical techniques | TBD | | |
| | Machine learning | TBD | | |
| | Physics based | TBD | | |
## Annex 2: Draft Taxonomy for Test and Experiment Design Domain

| Sub-domain                              | Entry Level descriptors                                                                 | Working Level descriptors                                                                 | Mastery Level descriptors                                                                 |
|-----------------------------------------|-----------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Design of experiment                    | Apply fully specified DOE                                                               | Develop an experimental design: replicates, environment, initial conditions                | Modify DOE process/constraints/metrics                                                     |
| Data Acquisition                        | Program Lab view or equivalent software                                                | Select hardware and software                                                               | Design and apply adaptive, multidiscipline, multi bandwidth methods                        |
|                                         | Set up and assemble physical devices                                                   | Define appropriate shielding and signal methods, alignment and calibration                  |                                                                                           |
|                                         | Assign sensors to appropriate hardware                                                 | Synchronize signals from multiple sensors                                                 |                                                                                           |
|                                         |                                                                                       | Define appropriate telemetry or remote methods                                             |                                                                                           |
| Inspection/ Evaluation                  | Apply known techniques at sub system level, non-destructive processes                  | Select appropriate technique(s) for a given component                                       | Develop novel techniques that combine multi-physics methods                                |
| Measurement Uncertainty analysis        | Estimate elemental contributions for conventional measurements                          | Develop propagated estimates for parameters made up of many elements                       | Devise new estimation and validation experiments                                          |
|                                         |                                                                                       | Develop calibration hierarchies                                                           | Develop novel estimation methods for complex systems                                       |
|                                         |                                                                                       | Develop elemental estimation methods for complex measurements                              |                                                                                           |
| Sensors                                 | Install sensors for basic measurements                                                | Select sensors to meet detailed requirements that are developed at a system level: resolution, bandwidth and repeatability | Design a new sensor from physic principles                                                |
|                                         | Interpret output signals                                                              |                                                                                           | Interpret complex interactions of sensors with environment                                 |
| *Integration                            | Design and assemble complex hardware and software experimental setups                  | Define and prioritize essential integration metrics and functions to achieve high level objectives: physical, mechanical, safety and, reliability | Optimize design for complex and conflicting constraints                                     |
|                                         | Select and source components                                                           | Design to meet cost effective criteria and appropriate complexity                          | Develop scalability methods                                                                |
| *Fault injection/insertion              | Conduct fully specified fault injection tests                                         | Apply existing fault modes in destructive and non-destructive ways                          | Design fault initiation and propagation methods                                           |
|                                         | Validate test results against baseline or reference data                               | Develop controlled simulations with system modifications:                               | Design and validate accelerated/aging test methods                                         |
|                                         |                                                                                       |                                                                                           |                                                                                           |
| Sub-domain       | Entry Level descriptors | Working Level descriptors                                                                 | Mastery Level descriptors                                                                 |
|------------------|--------------------------|-------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
|                  |                          | simple biases and ramps                                                                    | Design and develop correlation and validation methods                                          |
|                  |                          | Define limiting assumptions                                                                |                                                                                             |
|                  |                          | Apply relevant noise simulations                                                           |                                                                                             |
|                  |                          | Define and apply installation and environment effects                                       |                                                                                             |
|                  |                          | Interpret usage information to incorporate realistic test cases                           |                                                                                             |
| Data Validation  | Conduct functional and reality checks for conventional measurements                      | Design and conduct functional and reality checks for transient and dynamic data involving complex sensor suites | Design validation schemes for multidisciplinary processes                                      |
|                  |                          |                                                                                            |                                                                                             |
| Data Reduction   |                          |                                                                                            |                                                                                             |
| Data Management  | Manage multiple data sets ensuring providence and database compilation                   | Develop buffer and transmission designs                                                     |                                                                                             |
|                  |                          |                                                                                            | Define storage providence and database implementation methods                                |
### ANNEX 3: DRAFT TAXONOMY FOR COST BENEFIT ANALYSIS

| Sub-domain | Entry Level descriptors                                                                 | Working Level descriptors                                                                 | Mastery Level descriptors                                                                 |
|------------|-----------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Needs Analysis | Review requirements and stakeholders How to satisfy requirements                         | Refining requirements Review and refine stakeholders                                        | Defining requirements Define new stakeholders                                             |
| Risk Analysis | Identify known solutions likelihood of success and consequence Current company capabilities | Assess technology readiness level Identify risks and consequences                          | Analyze risk of novel approaches                                                          |
| Metrics, uncertainty/ confidence and evaluation (part of risk analysis?) | Capture data to facilitate evaluation                                                    | Evaluating performance against metrics                                                    | Setting metrics in conjunction with stakeholders                                         |
| Business Case | Given a business case template, enter applicable data                                     | Research existing business cases, find applicable model Apply and analyse impacts          | Create a business case model to use in a new novel scenario Design simulations to demonstrate/prove case |
| Support Service/ Performance Based Logistics approaches | TBD                                                                                       |                                                                                          |                                                                                           |
| Return On Investment | Plug in data to existing formulas                                                        | Identify required changes to business models Define “what if” scenarios                  | Creating new business models                                                              |
| Asset Management | TBD                                                                                       |                                                                                          |                                                                                           |
| Maintenance and the effect of prognostics management | TBD                                                                                       |                                                                                          |                                                                                           |
| Business versus customer perspective | TBD                                                                                       |                                                                                          |                                                                                           |