**Proceedings of the 11th Manufacturing Science and Engineering Conference**
**MSEC2016**
**June 27 – July 1, 2016, Blacksburg, Virginia, USA**

MSEC2016-8581

# TOWARDS BUSINESS PROCESS CATALOG FOR CLOUD-ENABLED SERVICE ORIENTED ARCHITECTURES

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## ABSTRACT

Advances in cloud-enabled service-oriented architectures (SOA) have caused a resurgence of industry interest in business process catalog as a vehicle for establishing shared references for collaborative business processes. With this paper, we start to explore the state of art and practice in business process catalog and classification scheme (BPCCS) development and use for the manufacturing industry. More specifically, this paper includes two major contributions. First, we identify a set of initial requirements for BPCCS. Second, we provide a use-case analysis based on the identified requirements. We end by comparing our BPCCS requirements with those being developed across other, BPCCS R&D groups.

## KEYWORDS

Business process, Catalog, Registry, Classification scheme, Cloud, Service-oriented architecture, Standards

## 1 INTRODUCTION

A new vision of agile systems development is materializing as new generations of cloud-enabled, Service-Oriented Architecture (SOA) systems emerge. In this vision, open eco-systems of service providers and customers form service marketplaces, which enable reuse of information and communication artifacts – business process models, service definitions, and their APIs (Application Programming Interfaces) – to achieve agile systems development

Standards Development Organizations (SDOs) play a key role in this new vision for systems development. The SDOs develop standard vocabularies, message schemas, process models, and other artifacts necessary for effective communication among the providers and customers, as in the Business-to-Business (B2B) manufacturing business processes. The Open Applications Group Inc. (OAGi) is one of the SDOs that provide these necessary artifacts – the Open Applications Group Integration Specification (OAGIS) and Business Object Document (BOD) specifications [1].

OAGi enables the vision of agile systems by supporting research and development allowing new industry use cases with reuse of information and communication artifacts. We are engaged within the OAGi Smart Manufacturing Working Group (OSMWG) to address such novel B2B use cases [2]. For example, in one of the use cases, the goal is to describe business processes and their components, using a messaging and scenario specification standard, for their subsequent retrieval and re-use when designing a new B2B scenario.

These and similar use cases rely on the assumption that shared terminological and conceptual references are readily available at the SDO and may be provided to the industry. This key technical capability, however, is hard to achieve in open eco-systems of service providers and customers. Business Process Catalog and Classification Scheme (BPCCS) is a promising approach to deliver this technical capability.

BPCCS is a system intended to provide to an open community of stakeholders shared definitions of concepts and terms for business processes that span across an enterprise and its multitier supplier network. Similar definitions of BPCCS (or, alternatively, business process repository or business process collection) are provided elsewhere [3–8]. Common to all of them is the notion of BPCCS enabling process knowledge sharing, aimed at integration standards, in the context of discovery and reuse of business processes. To support this, BPCCS consists of two main components: (1) a catalog, for storing business process models (including reference models); and (2) classification scheme, for classifying process models stored in the catalog, which allows encoding the context for an intended usage of the models (e.g., specifying functional actors and their activities that trigger and receive required integration messages). Both components include methods for managing the lifecycle of their content.

Although the advent of cloud-enabled Service-Oriented Architectures has brought along a renewed industry interest in BPCCS [9–11], which has also been investigated in both academic and industry communities [3,4,12,13] , there is still a lack of solutions that can be readily adopted for the B2B manufacturing enterprise use cases of interest. For that reason, the NIST Smart Manufacturing Design and Analysis Program (NSMDAP) [14], which explores Service-Oriented Architectures for Smart Manufacturing and composable (i.e., easily re-configurable) services and architectures, initiated investigation of BPCCS in support of the OSMWG goals.

Our research at OSMWG and NSMDAP is initially reviewing prior R&D work in industry and academia and synthesizing the BPCCS requirements space, followed by industry use case analyses. The main contribution of this paper is our report on results of the initial BPCCS requirements gathering and categorization followed by use case analyses based on the identified requirements space. In addition, we report on the work done to address these requirements by both academic (AR&D) and industry (IR&D) R&D or SDO groups.

We give an illustrative scenario next in which BPCCS helps manage business process evolution in cloud manufacturing. We continue by defining the role for the BPCCS that follow from the scenario. Then, we provide a categorization of BPCCS requirements. We follow by identifying, describing, and categorizing BPCCS requirements, and indicate work done by the four groups in addressing them. We provide an example BPCCS use case that further concretizes the requirements in the cloud services-based environment. Next, we provide a discussion of overlaps and differences in the work focus of the four R&D or SDO groups. The paper concludes with an outline of planned work to address BPCCS requirements.

## 2 A BPCCS SCENARIO: MANAGING BUSINESS PROCESS EVOLUTION IN CLOUD MANUFACTURING

Today, enterprises are looking to outsource to third party cloud providers both manufacturing and software services, reducing their costs and increasing the agility. In this endeavor, they have to constantly evolve their business processes as they become more complex. For example, what used to be a business process involving only internal organizations becomes partially exposed to external manufacturing organizations. Similarly, a business process involving only integrations between internal applications becomes now a process partially integrating with third party software services. Moreover, enterprises are increasingly global as they are now trading and partnering with companies across industries and around the globe. For these reasons, integrations in the cloud era become more complex and based on business-process-first rather than data-first basis. In such environment, the ability to analyze, categorize, and evolve business processes according to their usage context (such as geo-location and industry) and in a traceable manner becomes more important. The BPCCS is envisioned to meet these needs.

Fig. 1 shows a scenario where the BPCCS helps keep track of the BP evolution in the cloud manufacturing era. The texts on the arrow lines highlight some of the functionalities the BPCCS provides. Similar processes for qualifying materials for different types of products can be generalized into a reference BP with the BPCCS helping to do the mappings. The context classification schemes in the BPCCS help catalog these BPs; in this case, the product classification scheme may be used to classify the BP for Animal Feeds vs. the BP for Dairy Product. When looking into outsourcing the parts of a BP, the BPCCS can provide the reference BP along with its context information to help discover cloud services. Once services are discovered and procured, the original BP is modified. It can be cataloged using the same classification as the original BP. The original BP is kept for reference for the traceability purpose. The modified BP is used to drive the specific integration requirements such as the specific message definition, authentication, and security requirements. The modified BP shares the context with the original BP while adding these additional context properties.

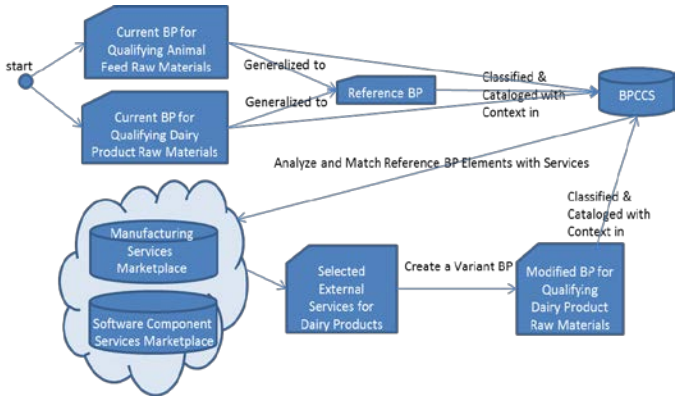


**FIGURE 1. BPCCS SUPPORTING BUSINESS PROCESS EVOLUTION IN CLOUD MANUFACTURING**

## 3 BPCCS ROLE

A Business Process Catalog and Classification Scheme (BPCCS) has a role of providing a shared vocabulary for naming the elements of various business process models (such as activities/subprocesses, roles, etc.), enabling discovery of these business process elements. A simple and generic example is given in Fig. 2, illustrating intended usage of BPCCS as a common way to describe activities from different organizations. Even though organizations P and Q use different ways of naming and describing their activities, by using a BPCCS catalog as shared vocabulary, they have a possibility to semantically align them (e.g. to identify that activities P1 and Q1 represents the same activity as both of them are mapped to the activity A from the BPCCS catalog). The BPCCS classification scheme supports this by providing multidimensional classification of business processes and activities along multiple contextual dimensions such as industry, role, location, etc. Consequently, the BPCCS classification scheme can be used to search and identify semantically equivalent activities and message exchanges (e.g., OAGIS BODs) used in the same or a similar context.

Besides this, additional use cases for BPCCS are possible. BPCCS may also be used to classify web services or Application Programming Interfaces (APIs) provided in a particular cloud ecosystem, based on the functionalities the services implement [15]. It may be used to provide context specification for Business Object Document (BOD) profiling, as used within the OAGi Semantic Refinement project [2].

In the context of providing and using a shared vocabulary, an organization-specific business process description is provided by associating its elements to semantically equivalent elements from a BPCCS catalog. This enables simple search for, say, web services that realize functionalities represented by the process elements, if the services were derived from implemented industrial business processes. Namely, by mapping the business process to a BPCCS catalog, each business process element would be related to the web services classified under the mapped BPCCS element(s).

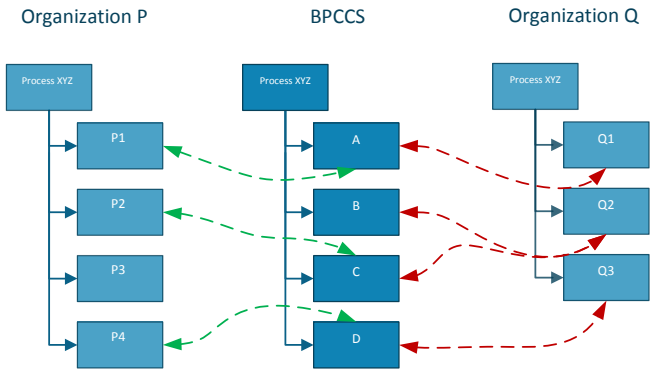


**FIGURE 2. USING BPCCS AS SHARED VOCABULARY**

## 4 BPCCS REQUIREMENTS CATEGORIES

BPCCS requirements categories, described next, have been synthesized from previous relevant [8,16,17] and cover expected BPCCS process model and tooling life cycle needs. The particular requirements (listed later in the paper) will be categorized in one or multiple categories.

- **BPCCS process model representation** includes requirements aimed at improving understandability of process examples in the catalog including handling process model complexity, references among model representations of functional participants, process storage and representation (external and/or internal), activities, message interface points, process metadata and other relevant information used to additionally describe processes.
- **BPCCS process model lifecycle management** includes requirements aimed at allowing users to create and revision process models using different mechanisms for reusing parts or the whole of existing process models (e.g., merging, composing, subsetting, extending), managing process model lifecycle, managing versions/variants and their evolution, which may lead to later definitions of roles.
- **BPCCS process model retrieval** includes requirements aimed at providing efficient navigation, search and query of the collection of processes using different mechanisms for process comparison, and indexing.
- **BPCCS process model evaluation** includes requirements aimed at providing required level of quality of process model using different mechanisms to check and measure model correctness, usability, compliance, and conformance to naming and structure conventions.
- **BPCCS integration** includes requirements (e.g., metadata interchange) aimed at supporting integration of BPCCS with external tools and repositories and association links to multiple BPCCSs hosted by different organizations.
- **BPCCS general requirements** includes requirements not specific to a business process model catalog, but common to any type of catalog or repository, such as access control, check-in/check-out, integrity management, reporting, etc.

In the following, we describe, and categorize the BPCCS requirements. Table 1 indicates work at the four R&D or SDO groups in addressing the requirements: we place '+', if the group has been addressing the requirement, or '-', otherwise; also, for the AR&D or IR&D groups, we provide specific references to the published work relevant to the requirements

### 4.1 Category 1: BPCCS Process Model Representation

**Representation at different levels of abstraction/granularity (R1):** BPCCS should provide classification scheme and description of business process model at different levels of details/abstraction, as the needed level of details of the business process depends on the reasons why the process is searched. For example, this will enable discovering

and comparing business processes in the early stages of business process analysis when higher level of abstraction is used and less details are necessary.

**Comprehensive business process description (R2):** BPCCS has to support comprehensive business process description that will cover different perspectives of the process, such as functional, behavioral, organizational, informational perspectives [18], business process context perspective [19], or process aspects identified in [17]. This description should include different contextual dimensions that will be used to define semantics of process and its activities more precisely and to facilitate their unambiguous interpretation. Some examples include roles participating in the business processes, business documents used and exchanged along with their structure definitions, pre- and post-conditions, triggering event, business function realized, etc.

**Formal and graphical representation of business processes (R3):** To precisely represent how an enterprise works identifying only its functions, sub-functions and activities is not sufficient. It is necessary to describe functions' interplay at operational level by defining execution constraints among them (i.e., execution flow, conditional execution, data exchange, events, etc.) [20]. For this purpose, graphical process modelling is used. Business process modeling integrates different perspectives from different stakeholders of a process within the resulting process definition, depending on capabilities of modelling technique used. Textual representations can be useful for simple processes, but graphical representations will increase the likelihood of correct representation, interpretation, and reuse of complex nested processes. Additionally, describing a business process using a process modeling standard like BPMN 2.0 supports automation of the process, either by direct execution by process-aware information system or by transforming it into an executable form [5,21].

**Dynamic/adaptive business processes (R4):** BPCCS should include business process models of dynamic nature, enabling last-minute changes to production by dynamic process configuration and "on the fly" process adjustments.

**TABLE 1. BPCCS REQUIREMENTS CATEGORIZATION AND WORK DONE AT R&D OR SDO GROUPS TO ADDRESS THE REQUIREMENTS**

| Category | Requirement | OSMWG | NSMDP | AR&D | IR&D |
|---|---|---|---|---|---|
| **BPCCS process model representation** | Representation at different levels of abstraction/granularity (R1) | + | + | [23];[5];[26];[16];[8]; [27];[28] | [13] |
| | Comprehensive business process description (R2) | + | + | [24]; [23]; [7]; [17]; [8] | [13]; [4] |
| | Formal and graphical representation of business processes (R3) | + | - | [23]; [7]; [5]; [8]; [16]; [27]; [29] | - |
| | Dynamic/adaptive business processes (R4) | + | + | - | [30] |
| | Different business process types (views) (R5) | - | - | [7]; [17] | - |
| | Different modelling languages support (R6) | - | - | [23]; [7]; [24]; [16]; [8] | [22] |
| **BPCCS process model lifecycle management** | Open & community-based development and maintenance (M1) | + | + | [7]; [5]; [24]; [8] | - |
| | Bottom-up development and maintenance (M2) | + | + | [16] | - |
| | Industry-specific & cross-industry classification schemas and business process models (M3) | + | + | [23]; [7]; [8] | [4] |
| | Adaptation/customization mechanism (M4) | - | + | [25]; [7]; [16]; [8]; [31] | - |
| | Version management & evolution and change methodology (M5) | - | + | [23]; [24]; [8]; [17]; [27]; [32] | - |
| | Analysis of process model similarities and differences (M6) | - | + | [23]; [24]; [33]; [8]; [16]; [34]; [35]; [36] | - |
| **BPCCS Process Model Retrieval** | Cross-reference between different classification schemas (T1) | + | - | [25] | - |
| | Complex mapping types (T2) | + | + | - | [37] |
| | Analysis of process model similarities and differences (T3) | (Same as M6) | | | |
| | Multi-facet search (T4) | + | - | [24]; [8] | [13] |
| **BPCCS Process Model Evaluation** | Efficient mechanism to evaluate BPCCS content quality (E1) | - | - | [16]; [8] | - |
| | Analysis of process model similarities and differences (E2) | (Same as M6) | | | |
| **BPCCS Integration** | Integration with external catalogs and tools (I1) | - | - | [8]; [17] | - |
| | Multiple interfaces provided (I2) | - | - | [24]; [17] | - |
| **BPCCS General Requirements** | General catalog management functions (G1) | - | - | [8]; [17]; [24]; [7]; [16]; [32] | - |

**Different business process types (views) (R5):** BPCCS should provide mechanisms for defining different types of processes. Using BPMN-like terminology, that would be: (1) Single process (single pool) including (1.a) Private (internal) view – all activities performed inside an organization; (1.b) Public (external) view – only activities used to interact with other participants; and (2) Collaborative process (multiple pools) - multiple processes and their interactions.

**Different modelling languages support (R6):** BPCCS should support at least one common B2B messaging standard (e.g. OAGIS) and support at least one process modeling language (e.g. BPMN) [22]. It is desirable to support as many process modeling languages as possible (e.g. BPMN, UML activity diagrams, EPC, YAWL, etc.) to increase understanding of process models, but this is not recognized by stakeholders as a necessary requirement (see [23]).

Ideally, process models should internally be stored independently of any process modeling languages, making BPCCS independent from specific technology (e.g., canonical model in [16]). Then, different modelling languages can be treated as different syntax representations of the same process model. To satisfy our goals such internal independent representations must semantically be rich enough, to support all possible concepts used in all supported modelling languages.

### 4.2 Category 2: BPCCS Process Model Lifecycle Management

**Open & community-based development and maintenance (M1):** Most of the existing repositories and catalogs are proprietary, maintained solely by their owners [8]. However, better adoption of and alignment with a proposed classification scheme and business process models can be achieved by inclusion of targeted users in the process of BPCCS content creation and management. BPCCS should enable development of the classification scheme and process models by providing an open, distributed community of users mechanisms for collaborative creation and maintenance of classification scheme and business process models.

**Bottom-up development and maintenance (M2):** BPCCS should provide mechanisms for an incremental and adaptive approach that, in addition to top-down guidance and a meta-model-defined architecture, also provides bottom-up creation and evolution of the classification scheme and business process models. As the classification scheme and business process model will be created collaboratively by an open community, an efficient mechanism is necessary to converge and harmonize different inputs (i.e., variants and adaptations by different users) to a single output (i.e., a complete and unambiguous classification scheme and business process models).

**Industry-specific & cross-industry classification schemes and business process models (M3):** BPCCS should support storing classification schemes and business processes regardless of their domain or industry. Both cross-industry (general) and industry-specific (domain-specific) classification schemes and business processes must be supported. In industry-specific, we also include proprietary, company-specific classification schemes.

**Adaptation/customization mechanism (M4):** BPCCS must provide means for a user to adapt and use the adapted classification scheme and process models for industry- or enterprise-specific requirements. At least two ways of adaptation should be supported: (1) Subsetting – instead of "all or nothing" approach that includes usage of whole business processes and whole business documents, user can make a subset of BPCCS processes or business documents as it best fits his needs; (2) Extending - allows inclusion of new concepts that addresses specific needs of specific industry or specific enterprise. Unambiguous extension mechanism and procedure have to be formally defined and used uniformly across all adaptations of classification scheme and process models.

**Version management & evolution and change methodology (M5):** BPCCS should provide support for storing both original and adapted schemes and processes, i.e. storing multiple versions of schemes and processes (cross-industry, industry-specific or enterprise-specific processes).

BPCCS should enable versioning and evolution of classification schemes and business process models. BPCCS should provide both mechanisms to manage evolution and change within catalog as well as methodology and guidelines to conduct them. For example, in the case of business process classification, to specify: (1) how cross-industry scheme can be extended to create industry-specific scheme; (2) how to check if some changes should be propagated to the cross-industry scheme when industry-specific schemes are evolving by changing existing ones or adding a new one; (3) how to enable synchronized coevolution of industry-specific classification schemes guided from single, central point (cross-industry classification scheme). Independent, unsynchronized evolvement will introduce redundancy and inconsistency across industry-specific classification schemes.

**Analysis of process model similarities and differences** (also categorized under Business Process Model Retrieval and Business Process Model Evaluation categories.) **(M6):** BPCCS should provide a mechanism for either manual or automatic analysis of similarities between process models, as it supports multiple features. For example, it enables easy retrieval of process models [8]. Besides that, a similarities analysis mechanism should be useful for adaptation/customization process, as well as a potential base for semi-automated bottom-up creation of classification scheme and process models. Also, it can provide support for efficient model search (e.g., combined with indexing or clustering approaches), new process design by re-use, reengineering, maintenance, etc.

### 4.3 Category 3: BPCCS Process Model Retrieval

**Cross-reference between different classification schemes (T1):** To facilitate navigation and browsing of processes and activities, BPCCS will provide their categorization based on the BPCCS multi-dimensional classification scheme. Besides being defined internally within BPCCS, the list of possible values for

each context dimension of BPCCS classification scheme can be covered by multiple classifications or taxonomies. Consequently, usage of different classifications should be supported by BPCCS. So, BPCCS should maintain cross-reference mappings between its components and components of classifications defined by other standard organizations. Establishing cross-reference relationships between them will facilitate end users to easily navigate, find and retrieve processes and their activities from BPCCS using classifications that are most familiar to them. Basically, users will search BPCCS using the classification scheme to which they are used to, while their choices will be "translated" to corresponding BPCCS classification scheme components for description of their processes.

Most sources ([4][23][7][24][8][3][13]) point out the need to classify processes by some classification scheme. Some of them define a scheme that should be used. For example, [4] and [8] impose usage of Porter's Value Chain and Open-EDI. Only [25] mentions the need for cross-referencing different classification schemes (i.e., "bridging of different taxonomies based on concepts in the field of ontologies").

**Complex mapping types (T2):** Both cross-reference mappings and mappings established between BPCCS and enterprise-specific processes (when those processes are described using BPCCS terms) must be supported by BPCCS. In the simplest case, established mappings will be defined as one-to-one relations, but it can be expected that multitudes of mapping types would be necessary and BPCCS will have to support their definition and usage. Besides different nature of established mappings (e.g., generalization/specialization, decomposition/aggregation, etc.), mapping types will differ based on their complexity. For example, one element may need to be mapped to two or more elements (one-to-many), sometimes more than one element has to be mapped to one element (many-to-one), or sometimes corresponding element cannot be identified. Also, some mapping types will have complex structure, i.e., they will contain other expressions.

**Analysis of process model similarities and differences (T3)** (also categorized under Business Process Model Lifecycle Management and Business Process Model Evaluation categories.) (See description under Business Process Management category.)

**Multi-facet search (T4):** Besides browsing and simple lexical search, other means of searching and finding appropriate processes and activities should be provided by BPCCS. For this purpose different facets or tags could be used. Basically, all identified contextual dimensions used for process description can be used as criteria for multi-facet search, while additional facets can be defined as needed.

### 4.4 Category 4: BPCCS Process Model Evaluation

**Efficient mechanism to evaluate BPCCS content quality (E1):** As the classification scheme and business process models will be created collaboratively, in a combined top-down/bottom-up manner, it is necessary to evaluate if the result of that process is correct, complete and unambiguously defined. BPCCS should provide appropriate evaluation mechanism.

**Analysis of process model similarities and differences (E2)** (also categorized under Business Process Model Lifecycle Management and Business Process Model Retrieval categories.)**:** See description under Business Process Management category.

### 4.5 Category 5: BPCCS Integration

**Integration with external catalogs and tools (I1):** It should be possible to access and share process models with external catalogs and to integrate BPCCS with different external tools, such as process modeling tools; report generators; process analysis tools; workflow engines; and collaboration tools.

**Multiple interfaces provided (I2):** BPCCS should provide different interfaces to call its functions, including graphical interface; Web service APIs; and Implementation-specific public APIs.

### 4.6 Category 6: BPCCS General Requirements

**General catalog management functions (G1):** BPCCS should provide mechanisms that realize general catalog management functions, including Access management, Integrity management, Transaction management, Check-in/check-out (locking) management, and Notification management.

## 5 EXAMPLE BPCC USE CASE

As we gather and analyze specific industry Smart Manufacturing use cases, we use the identified requirements space to refine use cases currently of interest at the OSMWG and NSMDAP. In the following, we look at the ***Design B2B Manufacturing Business Process Using OAGIS*** use case, noting relevant requirements from the previously identified collection (using requirements identifiers, e.g., [R1]).

In this use case, we dealt with models of business process (BP). The purpose is to start with a B2B Manufacturing BP and establish how the business process entities may be described at the right level of detail and how OAGIS scenarios and Business Object Documents (BODs) – the selected Manufacturing Scenario and Messaging Content Standard – can be described and discovered/matched for (manual) reuse.

This use case includes five other use cases described next: (1) Create/Adopt Classification Scheme; (2) Create OAGIS scenario and BOD catalog entry (given a Classification Scheme); (3) Use OAGIS scenario and BOD catalog to design a manufacturing BP; (4) Manage OAGIS scenario and BOD catalog entries (given a Classification Scheme); and (5) Manage Classification Scheme changes and updates.

***Use Case 1.1: Create/Adopt Classification Scheme*** is where we create or adopt an existing Classification Scheme to help identify business process entity types. The Classification Scheme (CS) may have multiple dimensions, such as business process element type, information exchange entity type,

function type, etc [R2]. CS may have multiple abstraction levels, enabling its use in early or later stages of business process design [R1].

An example: The *APQC Process Classification Framework (PCF)* – an existing manufacturing functional classification framework – is adopted as a Classification Scheme for the BP catalog. The Classification Scheme (CS) is reviewed for relevance and appropriateness for the target B2B Manufacturing Business Process design. Specifically, the *APQC PCF* classification of business process elements at the Activity and Task level is checked for relevance for the target BP. For example, the relevant *APQC PCF* classes include *Deliver Product and Services* (Process Category 4), which in turn includes *Plan and Acquire Necessary Resources* (Process Group 4.1), which contains *Create and Manage Master Production Schedule* (Process 4.1.4), which contains *Manage Work-in-Progress Inventory* (Activity 4.1.4.2).

***Use Case 1.2: Create OAGIS scenario and BOD catalog entry (given Classification Scheme)*** is where we create catalog entries for selected standard business process entity types, using the identified Classification Scheme. The catalog entries are defined using a selected standard specification, such as the OAGIS scenarios and their corresponding BODs, which may use a classification that differs from the one created/adopted in Use Case 1.1 [T1, M3]. In the absence of formalized, model-based definitions of these entity types, their informal, human-readable descriptions are analyzed for mapping onto the Classification Scheme classes. Through human analyst's interpretation, labels associated with business process entity types are mapped to appropriate CS classes [T2, T3]. In the case the CS classification does not provide sufficiently refined set of classes, introduction of additional levels of classification is provided for precise mapping of the business process entity types [R1, R2, M2].

An example: Although OAGIS scenarios are non-normative part of the OAGIS standard, they provide useful information to design business processes, identify relevant BODs, and help planning for BOD reuse. First, OAGIS provides categorization of scenarios, such as *Manufacturing*, *Supply Chain Integration*, and *Purchasing*, which indicate candidate scenarios for the target B2B Manufacturing BP. Second, OAGIS scenarios' labels imply relevance to the target manufacturing BP, such as Scenario 42 – *Production to Manufacturing Execution System (MES)*. Third, the OAGIS scenarios' participant labels indicate that the scenario is relevant to specific parts of the target manufacturing BP; for example, in Scenario 42, participants include *Order Management, Inventory, Engineering-PDM, Manufacturing (ERP), Manufacturing Execution (MES), and Costing*. Fourth, some scenarios include definition of process events that are related to other process elements; for example, within Scenario 42, *SyncBillofMaterials (SyncBOM)* BOD is issued between two participants whenever a BOM change or update event occurs; *ProcessIssueInventory* BOD is issued whenever an Inventory change or update event occurs; and *Get/ShowWIPStatus* BOD is issued whenever production event needs to be noted by the participants.

To create an OAGIS scenario and BOD catalog entry for the given APQC PCF Classification Scheme (CS), we index the OAGIS/BOD entry using the CS Activity classes. Often, the case is that the APQC PCF Activity class corresponds to multiple OAGIS scenario/BOD entries. In that case, the CS Activity may be augmented with the Task subclasses (which refine Activity classes) in order to allow for more precise correspondence between OAGIS scenario/BOD entries and CS indices. In the case of OAGIS, we can use OAGIS scenario event descriptions to determine appropriate Task classes. For example, the CS Activity class *Manage Work-in-Progress Inventory* activity may be refined with *BOMIssue*, *InventoryIssue* and *WIPStatus* Task classes to correspond to the OAGIS *Scenario 42/SyncBOM* BOD, *Scenario 42/ProcessIssueInventory* BOD and *Scenario 42/WIPStatus BOD*, respectively.

***Use Case 1.3: Use OAGIS scenario and BOD catalog to design a manufacturing BP*** is where we design a target manufacturing business process by identifying relevant OAGIS scenario and BODs. Initially, a human BP analyst analyzes the target manufacturing business process to arrive at meaningful and manageable elements of the business process [T3]. The goal is for the business process elements to be mapped onto the CS classes, which, presumably, have associated OAGIS scenarios and BODs [R1, R2, T1, T2]. Following the associations, the business process entities are provided relevant OAGIS scenarios and BODs [T1, M3]. In case such associations are lacking, an identified gap in the standard specification is identified and communicated to the SDO.

An example: In the target B2B Manufacturing Business Process, the OEM (Original Equipment Manufacturer) Procurement/Supplier Management department decides to buy parts from a supplier based on the OEM's Engineering Product Design department's part designs. The OEM communicates Bill of Materials (BOM) documentation to the Supplier, where it is received by the Engineering Product Design department (along with other model and specification documentation).

This B2B Manufacturing BP task of communicating BOM documentation may be readily mapped to the APQC PCF Classification Scheme Activity 4.1.4.2 *Manage Work-in-Progress Inventory* and its Task *BOMIssue*. As discussed previously, this CS Activity/Task is mapped to OAGIS *Scenario 42/SyncBOM* BOD, which, in turn, allows identification of the OAGIS scenario/BOD pair as relevant to the target B2B Manufacturing BP.

***Use Case 1.4: Manage OAGIS scenario and BOD catalog entries (given a Classification Scheme)*** is where we extend or somehow change the OAGIS scenario and BOD catalog entries. In case there is a gap in the standards specification, a new or updated OAGIS scenario and/or BOD may be developed, followed by their inclusion as a new or updated catalog entry

(employing Use Case 1.2). No new BPCCS requirements are introduced.

An example: In the target B2B Manufacturing Business Process, the OEM (Original Equipment Manufacturer) Procurement/Supplier Management department buys designed parts from a supplier and needs to communicate Inspection Definition documentation to the Supplier, where it is received by the QA Inspection/Audit Definition department. The current OAGIS standard does not support the BP element and a new OAGIS scenario and *ProcessInspectionOrder* BOD are developed, followed by their inclusion as a new catalog entry.

***Use Case 1.5: Manage Classification Scheme changes and updates*** is where we change or update the current Classification Scheme. As described in Summary of Use Case 1.2, there may be a need to update Classification Scheme due to need to precisely identify specific business process entities in the target manufacturing BP, but there are potentially many other involved management situations [M2, M4, M5].

An example: See Use Case 1.2 for a simple situation where the need for CS update management arises.

## 6 A COMPARATIVE ANALYSIS OF BPCCS REQUIREMENTS-DRIVEN WORK AT FOUR R&D AND SDO GROUPS

As we identify key requirements for our use cases and layout approach for BPCCS, it is useful to compare work focus at the four groups/programs – the NIST Smart Manufacturing Design and Analysis Program (NSMDAP), the OAGi Smart Manufacturing Working Group (OSMWG), the Academic R&D Community (AR&D), and Industrial R&D Community (IR&D) – based on their respective interests in addressing subsets of the identified BPCCS requirements. Here are some observations following comparison of the entries in Table 1.

- **NSMDAP and OSMWG have shared interest in BPCCS requirements.** The NIST Smart Manufacturing Design and Analysis Program (**NSMDAP**), by way of its interest in Service-Oriented Architectures (SOA) for Smart Manufacturing, has been actively collaborating with the OAGi Smart Manufacturing Working Group (**OSMWG**). It comes as no surprise then that there is significant overlap between the BPCCS requirements under investigation in the two groups.
- **NSMDAP addresses some critical requirements beyond OSMWG interest.** Some of the more challenging topics, which are considered by **NSMDAP** to be key in achieving SOA for Smart Manufacturing, such as *Adaptation/customization mechanism*, *Version management & evolution and change methodology*, have not been taken on by the **OSMWG**. This is understandable and appropriate as these issues require significant, multi-year research effort to determine feasibility of alternative approaches and their relative risks with respect to the current and rapidly changing manufacturing application space for manufacturing and cloud capabilities. **NSMDAP** is undertaking such high-risk, high-return research based on industry input.
- **NSMDAP doesn't address some of the requirements at OSMWG.** Some of the requirements considered by the **OSMWG** have not been included in **NSMDAP** work, such as *Formal and graphical representation of business processes* or *Multi-facet search*. While challenging, these requirements have been addressed by a number of efforts in academic community or they may not be on a critical path to achieving SOA for Smart Manufacturing.
- **AR&D has limited engagement with certain critical requirements.** Some of the critical requirements considered by both **OSMWG** and **NSMDAP**, such as *Dynamic/adaptive business processes* and *Complex Mapping Types* have not been addressed at all by the Academic R&D community with research interest in BPCCS. Or, as in the case of *Bottom-up development and maintenance*, the requirement has been considered to a limited extent.
- **Some AR&D requirements are of limited interest at OSMWG & NSMDAP.** A number of requirements, including *Efficient mechanism to evaluate BPCCS content quality*, *Different business process types (views)*, *Different modelling languages support*, *Integration with external catalogs and tools*, *Multiple interfaces provided*, *and General catalog management functions*, are of limited interest by **OSMWG** and **NSMDAP**. Some of requirements are assumed as default in the two groups (e.g., general repository), while others are implementation related, which are not being addressed yet, and yet others are subject of specific work scope definition (e.g., OAGIS and BPMN).
- **Prior IR&D addressed to limited extent critical requirements but new IR&D takes broader look.** Industry R&D work of the last 10-15 years has not addressed some of critical requirements for BPCCS to any significant extent, including *Open & community-based development and maintenance* and *Bottom-up development and maintenance.* However, presently *Dynamic/adaptive business processes*, and *Complex mapping types* are among some of the critical requirements being addressed by IR&D efforts, such as Industrie 4.0 [30] and others.

## 7 CONCLUSIONS

In this paper, we identified, categorized, and clarified with selected use case, requirements from the current state of art and practice in Business Process Catalog and Classification Scheme (BPCCS) research, which is considered a potentially significant enabler of cloud-enabled service-oriented architectures.

Our active involvement in a Smart Manufacturing research program, on one hand, and a Standard Development Organization's (SDO's) strategy and research group in Smart Manufacturing, on another, motivated us to identify both

industry needs and requirements in state of art in business process catalog research. Within the Smart Manufacturing research program we are advancing the standards development processes for efficient creation and adoption of standards for agile, Smart Manufacturing (SM) systems development processes. In parallel, at the SDO's SM Working Group, we witness industry interest to advance standards development processes to enable such agile systems development.

Consequently, our research and development in both of these groups is increasingly focused on the Business Process Model Lifecycle Management requirements category. Both groups have overlapping interest in addressing user-driven requirements in this category, such as *Open & community-based development and maintenance* or *Bottom-up development and maintenance*. In addition to that, within the SM research program, there is a significant focus on research into enabling mechanism-focused requirements in this category, such as *Adaptation/customization mechanism* and *Version management & evolution and change methodology*,

As the two groups continue to pursue their collaborative agendas, in the near term there will be important focus on elaborating BPCCS requirements for specific industry Smart Manufacturing use cases. We plan experimental work to assess state of art and practice approaches with respect to the requirements identified in the industry SM use cases of interest. At that time, we look to identify and assess relevant research from both academic and industry groups.

## ACKNOWLEDGMENTS

Any mention of commercial products is for information only; it does not imply recommendation or endorsement by NIST.

## REFERENCES

[1] "OAGi" [Online]. Available: www.oagi.org. [Accessed: 01-Dec-2015].

[2] "OAGi Working Groups" [Online]. Available: http://www.oagi.org/dnn2/OurCommunity/WorkingGroups.aspx. [Accessed: 27-Nov-2015].

[3] Malone, T. W., Crowston, K., Lee, J., Pentland, B., Dellarocas, C., Wyner, G., Quimby, J., Osborn, C. S., Bernstein, A., Herman, G., and others, 1999, "Tools for inventing organizations: Toward a handbook of organizational processes," *Management Science*, **45**(3), pp. 425–443.

[4] UN/CEFACT International Trade Business Process Group (TBG 14), 2005, "UN/CEFACT - Common Business Process Catalog Technical Specification," UN/CEFACT.

[5] Wohed, P., Zdravkovic, J., and Johannesson, P., 2007, "A Universal Repository for Process Models," Stockholm: Department of Computers and Systems Science.

[6] Ma, Z., Wetzstein, B., Anicic, D., Heymans, S., and Leymann, F., 2007, "Semantic Business Process Repository.," *SBPM*, **251**.

[7] Bhagya, R., Vasanthapriyan, S., and Jayaweera, P., 2014, "Survey on Requirements and Approaches of Business Process Repositories," *International Journal of Scientific and Research Publications*, p. 236.

[8] Elias, M., 2015, "Design of Business Process Model Repositories: Requirements, Semantic Annotation Model and Relationship Meta-model," Ph.D. thesis, Department of Computer and Systems Sciences, Stockholm University.

[9] "Business Process Management and Cloud Computing" [Online]. Available: http://www.oracle.com/oms/oracleday/business-process-management-1366303.pdf. [Accessed: 27-Nov-2015].

[10] "What happens in a service oriented world?" [Online]. Available: http://community.hpe.com/t5/Cloud-Source/What-happens-in-a-service-oriented-world/ba-p/6790100#.VliCSXarSUk. [Accessed: 27-Nov-2015].

[11] "OpenText Cloud Service Brokerage and BPaaS for the Enterprise" [Online]. Available: http://mimage.opentext.com/alt_content/binary/pdf/Cloud-Service-Brokerage-and-BPaaS-for-the-Enterprise-Collateral-Solution-Overview.pdf. [Accessed: 27-Nov-2015].

[12] Techniques & Methodologies Working Group (TMWG), 1997, "Detailed Project Plan For Modelling and Developing The Next Generation of EDI Standards," UN/CEFACT.

[13] ebXML Business Process Project Team, 2001, "ebXML Catalog of Common Business Processes v1. 0," UN/CEFACT and OASIS.

[14] "Smart Manufacturing Systems Design and Analysis Program" [Online]. Available: http://www.nist.gov/el/msid/syseng/smsda.cfm. [Accessed: 27-Nov-2015].

[15] Ameri, F., Kulvatunyou, B., and Ivezic, N., 2015, "A Formal Process for Community-Based Reference Model Evolution for Smart Manufacturing Systems," *Advances in Production Management Systems: Innovative Production Management Towards Sustainable Growth*,

Springer, pp. 30–38.

[16] La Rosa, M., Reijers, H. A., van der Aalst, W. M. P., Dijkman, R. M., Mendling, J., Dumas, M., and Garcia-Bañuelos, L., 2011, "APROMORE: An advanced process model repository," *Expert Systems with Applications*, **38**(6), pp. 7029–7040.

[17] Yan, Z., Dijkman, R., and Grefen, P., 2012, "Business process model repositories-Framework and survey," *Information and Software Technology*, **54**(4), pp. 380–395.

[18] Curtis, B., Kellner, M. I., and Over, J., 1992, "Process modeling," *Communications of the ACM*, **35**(9), pp. 75–90.

[19] List, B., and Korherr, B., 2006, "An evaluation of conceptual business process modelling languages," *Proceedings of the 2006 ACM symposium on Applied computing*, pp. 1532–1539.

[20] Weske, M., 2012, *Business process management: concepts, languages, architectures*, Springer Science & Business Media.

[21] Indulska, M., Green, P., Recker, J., and Rosemann, M., 2009, "Business process modeling: Perceived benefits," *Conceptual Modeling-ER 2009*, Springer, pp. 458–471.

[22] Johnson, M., 2015, "Enabling Contract Manufacturing in the Cloud," *OAGi-NIST Workshop on Open Cloud Architectures for Smart Manufacturing 2015*.

[23] Shahzad, K., Elias, M., and Johannesson, P., 2010, "Requirements for a business process model repository: A stakeholders' perspective," *Business Information Systems*, pp. 158–170.

[24] Eid-Sabbagh, R.-H., Kunze, M., and Weske, M., 2012, "An open process model library," *Business Process Management Workshops*, pp. 26–38.

[25] Hofreiter, B., Huemer, C., and Klas, W., 2002, "ebXML: Status, research issues, and obstacles," *Research Issues in Data Engineering: Engineering E-Commerce/E-Business Systems, 2002. RIDE-2EC 2002. Proceedings. Twelfth International Workshop on*, pp. 7–16.

[26] Malone, T. W., Crowston, K., and Herman, G. A., 2003, *Organizing business knowledge: the MIT process handbook*, MIT press.

[27] Fantinato, M., Toledo, M. B. F. de, Thom, L. H., Gimenes, I. M. de S., Rocha, R. dos S., and Garcia, D. Z. G., 2012, "A survey on reuse in the business process management domain," *International Journal of Business Process Integration and Management*, **6**(1), pp. 52–76.

[28] Holschke, O., Rake, J., and Levina, O., 2009, "Granularity as a cognitive factor in the effectiveness of business process model reuse," *Business Process Management*, Springer, pp. 245–260.

[29] Aldin, L., and de Cesare, S., 2011, "A literature review on business process modelling: new frontiers of reusability," *Enterprise Information Systems*, **5**(3), pp. 359–383.

[30] Industrie 4.0 Working Group, 2013, "Recommendations for implementing the strategic initiative INDUSTRIE 4.0," Platform Industrie 4.0.

[31] Shahzad, K., Andersson, B., Bergholtz, M., Edirisuriya, A., Ilayperuma, T., Jayaweera, P., and Johannesson, P., 2009, "Elicitation of requirements for a business process model repository," *Business Process Management Workshops*, pp. 44–55.

[32] Lazarte, I. M., Thom, L. H., Iochpe, C., Chiotti, O., and Villarreal, P. D., 2013, "A distributed repository for managing business process models in cross-organizational collaborations," *Computers in Industry*, **64**(3), pp. 252–267.

[33] Qiao, M., Akkiraju, R., and Rembert, A. J., 2011, "Towards efficient business process clustering and retrieval: combining language modeling and structure matching," *Business Process Management*, Springer, pp. 199–214.

[34] Jin, T., Wang, J., La Rosa, M., Ter Hofstede, A., and Wen, L., 2013, "Efficient querying of large process model repositories," *Computers in Industry*, **64**(1), pp. 41–49.

[35] Kunze, M., and Weske, M., 2011, "Metric trees for efficient similarity search in large process model repositories," *Business process management workshops*, pp. 535–546.

[36] Jung, J.-Y., Bae, J., and Liu, L., 2009, "Hierarchical clustering of business process models," *International Journal of Innovative Computing, Information and Control*, **5**(12), pp. 1349–4198.

[37] CEN/TC BII, 2015, "Business Interoperability Interfaces for Public Procurement — Guideline on the Usage of Classification Systems," CEN.

 