Semantic Representation of Innovation, Generic Ontology for Idea Management

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***Abstract*—Innovation is currently recognized as an essential competitive enabler for any organization that wants to survive and grow. In addition, organizations feel a growing need to open up their internal innovation processes and to integrate innovation management tools. But, due to the distributed and heterogeneous characteristics of innovation knowledge, it becomes more difficult to manage the innovation process effectively and efficiently. However, the emerging and rapid development of semantic web technologies brings new opportunities. In this paper, a novel modular ontology that provides a semantic representation of innovation and a common language to foster interoperability, declarativity, and intelligent services between tools and to support the innovation life cycle is introduced. Our Innovation Management Ontology consists of three sub-ontologies that refer to three factors, which are: innovation core -Idea-, innovation actor and innovation context, we have identified as cornerstones of any successful innovation.**

***Index Terms*—innovation management, open innovation, knowledge interoperability, semantic representation, modular ontology**

I. Introduction

Innovation management is crucial for organizations to survive and succeed in the current competitive environment. Many organizations have become more aware of external knowledge and technology to maintain their competitiveness in the global market. Henry Chesbrough defines this new imperative as 'Open Innovation', which accelerates internal innovation of organizations by using actively purposive inflows and outflows of knowledge, external ideas as well as internal ideas, internal and external paths to market, as they look to advance their technology [1].

To achieve successful innovation in an open context, it is necessary to overcome the challenge of integration of distributed and heterogeneous information systems. Semantic web technology is a promising direction for such challenge. Its primary goal is to facilitate interoperability between various tools necessary to support the full life cycle of innovation in an open context. Furthermore, the use of semantic technologies enables advanced management functions like semantic reasoning and automatic analysis.

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As the backbone technology for the Semantic Web, ontologies promise a share and common understanding of a domain that can be communicated between people and application. Ontologies as explicit specifications of conceptualizations [2] provide a common language, i.e., a common data interchange format to support the interoperability and facilitate access and reuse of knowledge.

The reminder of this paper is structured as follows: First, we highlight the arising relationship between Innovation or more precisely Open Innovation and Semantic Technologies (Section II). Next, in Section III we provide the theoretical background by discussing the three factors we identified as cornerstones of any successful innovation. Then, we review the existing innovation ontologies (Section IV). In Section V we develop our generic modular ontology for innovation representation and management, before we conclude in Section VI.

II. Open Innovation & Semantic Technologies

In the increasingly competitive market that characterizes the world economy today, the need to develop innovations quickly has become the key driver of growth for many organizations. Open innovation model emerged as a response to this challenge.

A. Open Innovation

The interest in open innovation has been on the rise in both industrial and academic world. The benefits of open innovation have been established in several studies and surveys; A recent study by the UK Innovation Research Center indicates that those companies that are active in open innovation in both giving and receiving ideas achieve higher rates of innovation and of revenue growth [3]. In recent years, research on open innovation has been continuously spread into a variety of scopes; A search in Google Scholar on open innovation provides over than 2 million hits, Chesbrough's 2003 book has gathered more than 6,700 citations in just a decade (Google Scholar, Octobre 2013), and surprisingly a wide range of disciplines, including economics, psychology, sociology, and even cultural anthropology have shown interest in it [4]; All this indicates a positive response toward open innovation from both companies and researchers.

Open Innovation paradigm suggests that organizations can use both internal and external ideas and knowledge to be more efficient in creating and capturing value. But in

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an open context the complexity created by the explosion of richness and reach of knowledge has to be identified and managed to ensure successful innovation [5]. Likewise, more and more idea and innovation platforms appear on the Web, so it becomes imperative to integrate the innovation process with ICTs, to establish a common vocabulary to facilitate access and reuse of knowledge and to coordinate efficiently the actors in the innovation process. This is the concept of Interoperability.

B. Knowledge Interoperability

Interoperability is regarded as one of the key factors of existence of both people and organizations in knowledge society. According the US Joint Vision 2020 goal, interoperability is considered as a key element of information superiority [6].

Interoperability happens when two or more actors such as persons, organizations or systems interact, communicate or collaborate to achieve a common goal. A standard definition of interoperability is provided by the Institute of Electrical and Electronics Engineers -IEEE- as "… the ability of two or more systems or components to exchange information and to use the information that has been exchanged." This definition covers mainly the interoperability of data and information. As innovation is defined as a process wherein knowledge is acquired, shared and assimilated with the aim to create new knowledge, which embodies products and services [7]; And knowledge is defined as the state or asset that is achieved when "theory, information, and experience are integrated" [8]; Hence, Open Innovation will increasingly requires interoperability with a knowledge level perspective, well-known as knowledge interoperability.

The knowledge interoperability -KI-, as a powerful tool for the acquisition of new knowledge, aims to allow the transfer of knowledge between heterogeneous environments on the basis of shared, pre-established and negotiated meanings of information. The definition of KI is based on the understanding of knowledge as a tool for problem solving [9]. KI lies in the area of Semantics for constructing common understanding that will support and ease out the operations of sharing and spreading knowledge amongst various entities. In the last few years, Semantic Technologies have impacted the KM area by presenting a solution to knowledge codification.

C. Semantic Representation

Semantics is defined as the meanings of terms and expressions. Hence, Semantic Representation as a sub-field of Artificial Intelligence focuses on the formalization of knowledge, in order to create schemes that allow knowledge to be efficiently stored, modified, exchanged and reasoned.

In May 2001, Berners-Lee and al. introduced the concept of Semantic Web as a collection of standards and approaches for bringing order and meaning to information on the Internet [10]. Semantic Web Technologies enable the explicit representation of knowledge and its further processing to deduce new knowledge from implicitly hidden knowledge. Furthermore, the use of semantic techniques in the innovation management area brings with it the possibility to improve end-user efficiency by means of automated processing, and to cope with advanced analytical processing of innovation metadata through reasoning. Thus innovation managers can profit from better structured information, integration and data exchange across tools and platforms, and additional semantic reasoning that allows them to analyze ideas based on related concepts. To achieve these goals, Ontologies, which express knowledge in a certain vitality as well as in a machine interpretable form, were introduced.

D. Ontology

Ontologies are a foundational component of Semantic Technologies that provides a framework for "standardization of concepts and relationships used to describe and represent an area of knowledge" according to the World Wide Web Consortium -W3C-. An ontology is a representational artifact indicating the semantics of a given domain. Ontologies were developed in the field of Artificial Intelligence to facilitate knowledge sharing and reuse [11]. An ontology as ''a formal and explicit specification of a shared conceptualization'' [12], provides vocabularies about entities within a domain and their relationships, about the activities taking place in the domain and about the theories and elementary principles governing the domain. Moreover, ontologies encapsulate rules or logic for automated inference and reasoning, making it possible for applications or software agents to discover relationships and meaning not explicitly defined in the data [10]. In addition to these generic benefits, other particular benefits for the innovation management area can be expected as underpin search engines, information filtering, continual learning, better quality decision-making and ensure that the value and contribution of intellectual assets, as well as their effectiveness and their exploitation, is well understood.

III. Innovation Cornerstones

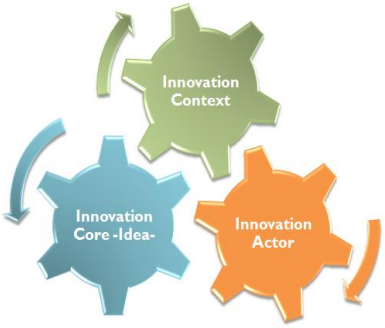

Figure 1. Innovation cornerstones.

It has been recognized that innovation management has evolved; thus, the new challenge that face the today's organizations is to get "the right *idea* to the right *actors* in the right *context*". Dealing with this challenge requires seamless connections among ideas as innovation cores, innovation actors and innovation context (Fig. 1). Such connections are required to support the emergence of vibrant communities that can exchange and effectively

use the full range of data, information, knowledge and wisdom.

The following of this paper discusses these three cornerstones of innovation and concludes by suggesting how they fit together into an overall ontology to guide an effective innovation management.

A. Innovation Core -Idea-

As reported by Amabile & al., "All innovation begins with creative ideas. We define innovation as the successful implementation of creative ideas within an organization." [7] In the innovation process, the stage of idea generation also called "ideation", whose objective is individual or collective identification of new ideas or opportunities, is often recognized as one of the highest leverage point for an organization. This first pillar of the innovation process is essential because without ideas, or rather without good ideas, there are few chances to have an innovation that can drive growth of organization.

B. Innovation Actor

It is often said that an innovative idea without a champion gets nowhere. Human capital as a "key ingredient to organizational success and failure" [13], and by all accounts increasingly important, has become the innovative organization's most vital resource.

When an innovative idea is expressed to others, it proliferates into multiple ideas because people have diverse skills, energy levels, frames of reference and interpretive schemas as a result of their back-grounds, experiences, and activities that occupy their attention and that filter their perceptions. These differing perceptions and frames of reference are amplified by the proliferation of transactions and relationships among people and organizational units that occur, as the innovation unfolds.

Moreover, motivated teams, composed of individuals with diverse expertise and experiences, usually accomplish much more than individual employees.

Hence, effective management of the innovation actors has become a critical issue for ensuring sustained innovation capacity.

C. Innovation Context

According to Griffin, the most successful innovative companies do not succeed merely by using one innovation approach more extensively or better, but by carefully selecting the right approach within a given context [14]. The context of innovation is not just about individual factors or organizational factors (as is done in many quantitative scientific studies focused on innovation); instead, it shall integrate the various contextual factors into a managerial framework.

A contextual approach can provide an overview of alternatives choices in different contexts and assist innovation actors in their innovation-related decision-making process, which in turn will make innovation processes more efficient. Nevertheless, innovation actors must have the freedom to make these adaptations and not be limited by corporate rules regarding innovation that contradict what their specific context demands.

D. Innovation Cornerstones vs Van de Ven Factors

In 1986, Van de Ven pointed out four central factors in the management of innovation: "new ideas", "people", "transactions" and "constitutional context" [15]. 20 years later, Van de Ven and Engleman still considered them as central in managing innovation [16], which means their imperativity. However, we think that Van de Ven has limited the scope of these factors because he considered only the management of: "ideas" into good currency, "people" attention, part-whole relationship in "transactions" and the institutional leadership in the "constitutional context". Moreover, for the "transactions" factor, we consider it is shared between the cornerstones "Actor" and "Context" that we have presented.

IV. Existing Innovation Representation

TABLE I. Overview of the Innovation Ontologies

Ontology	Features
Iteams Ontology Ning & al. (2006) [17]	- Facilitates distributed collection and development of ideas. - Relies on Semantic Technologies to allow integration of idea development tools. - Covers following features: Goals, Actions, Teams, Results and Community.
OntoGate Ontology Bullinger (2008) [18]	- Classified as Domain Ontology focusing on the early stage of innovation. - Aims at modeling the idea assessment and selection rather than providing technical integration. - Deduced from empirical research. - Offers a means to structure a company's understanding of the innovation process, in particular the inputs, outputs, participants, and assessment perspectives. - Covers three perspectives along which an idea or concept can be evaluated: market, strategy, and technology. - Presents a large number of modules.
Idea Ontology Riedl & al. (2009) [19]	- Classified as Application Ontology. - Aims at achieving interoperability across innovation tools by offering a common language for idea storage and exchange. - Does not provide a data model for representing individual ideas. - Provides a technical means to represent complex idea evaluations along various concepts.
GI2MO Ontology Westerski & al. (2010) [20]	- Classified as Domain Ontology. - Aims at serializing the IT systems data and enabling idea comparison regardless of the underlying IT system layer. - Aims at using semantic web technologies to interconnect data. - Developed based on a defined Idea Management life cycle. - Provides a formalization of metadata that can be used to describe ideas and associated information.

Although several research works currently deal with the innovation management, to our knowledge few of them explicitly aim at creating a common innovation ontology for the purpose of achieving interoperability. In

the following subsections, we will review and discuss existing ontologies providing a semantic representation of innovation with the goal of reusing them, if they are deemed suitable to meet the requirements we have defined, and understanding their strengths and weaknesses.

A. Overview of the Innovation Ontologies

An overview of the existing ontologies for innovation management is summarized in Table I.

B. Discussion

Conventionally, the evaluation of ontologies is based on the knowledge engineering approach. It makes use of a set of criteria of desirable qualities that has been evolved from the best practices in knowledge systems development to evaluate an ontology. These criteria often emphasize on the aspects of generality to enable ontology reuse [21]. In order to compare the presented ontologies and assess their merits to contribute to the definition of a new ontology for innovation management, we need to specify a set of ontology-comparison criteria and then check if each of them satisfies these criteria. Fox & al. and Gruber have proposed a number of criteria in order to evaluate ontologies [22]:

- Functional Completeness: Can the ontology represent the necessary information to support the management of the represented domain?
- Generality: To what degree is the ontology shared between diverse activities?
- Efficiency: Does the ontology support efficient reasoning, or does it require some type of transformation?
- Perspicuity: Is the ontology easily understood by the users so that it can be consistently applied and interpreted? Does the representation "document itself?"
- Precision/Granularity: Is there a core set of ontological primitives that are partitionable or do they overlap in meaning? Does the representation support reasoning at various levels of abstraction and detail?
- Minimality: Does the ontology contain the minimum number of objects (i.e., terms or vocabulary) necessary?

In our case, the criterion we have found the most important is "Functional Completeness" because it allows evaluating ontologies in respect to their purposes and their intended use. Moreover, as shown earlier (Section III), any representation of innovation that seeks to support its success must cover:

- Innovation core -Idea- management.
- Innovation Actors management.
- Innovation Context management.

Relatively to these cornerstones, a good representation of innovation should also ensure:

- Learning Management, because without learning, innovation may not occur [23].
- Resources Management, because the decisions that influence the extent to which innovation occurs are decisions about the allocation and management of resources [24].

Likewise, an effective management of actors involves:

- Activities Management.
- Roles Management.

Based on these 7 factors we evaluated the ontologies presented in the previous subsection. Table II offers a summary of this evaluation.

TABLE II. COMPARISON THE INNOVATION ONTOLOGIES

Model/Criterion	C 1	C 2	C3	C4	C5	C6	C7
Iteams Ontology	√	√	√	×	×	×	×
OntoGate Ontology	√	√	√	×	*	√	√
Idea Ontology	√	√	×	×	×	×	×
GI2MO Ontology	√	√	×	×	×	×	×

* Concept in order to develop it

We observe that the bulk of these ontologies do not respond or respond poorly to the defined factors. Thus, we decided to develop a new semantic representation of innovation, which provides innovative answers to the weaknesses found in existing ontologies.

V. GENERIC INNOVATION MANAGEMENT ONTOLOGY

It has been recognized that without addressing the reality of semantic heterogeneity, full seamless connectivity between the innovation's cornerstones highlighted above will not be achieved. To achieve this objective and relying on the gathered learning from the literature, a generic and novel ontology was developed.

A. Approach of Developpement

Manually constructing ontologies is a very demanding task, requiring a large amount of time and effort, even when principled solutions are used [25]. In order to reduce the complexity of designing and to facilitate the ontology reasoning, development, integration, maintenance and evolution [26], we decided to adopt a modular approach for the development of our ontology.

Modular Ontology refers to a methodological principle in ontology engineering. Modularization in itself is a generic concept that is intuitively understood as referring to a situation where simultaneously a thing (e.g. an ontology) exists as a whole but can also be seen as a set of parts (the modules) [27]. Hence, in the perspective of ontologies a module is a sub-ontology that can be connected to other sub-ontologies by integration and would be able to interact among each other.

In our case we developed three sub-ontologies referring to the three cornerstones of innovation we highlighted above; then, we proceeded to their integration using an ontology mapping process, which consists in finding common concepts between the sub-ontologies to build the mother ontology, we called Innovation Management.

B. Ontology Design

To design our ontology and to model the data structure of the innovation domain, we started by analyzing the

data based on the research done on the definition of our Innovation Management Life Cycle (Fig. 2) and we have looked into published data from some operational Idea and Innovation Management Systems (e.g. IdeaScale, GI2MO IdeaStream and others).

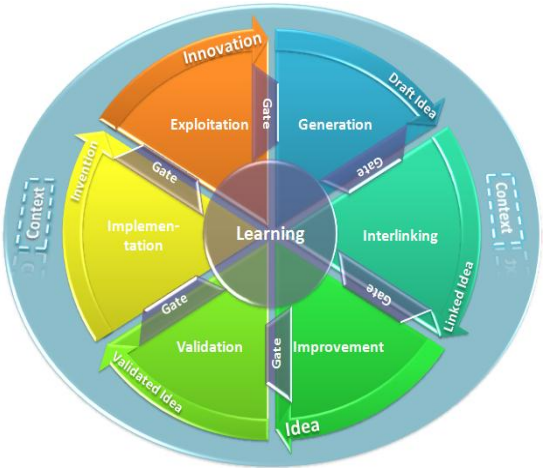

Figure 2. Innovation management life cycle [7].

The overview of main concepts and relationships included in the Innovation Management Ontology is shown in Fig. 3.

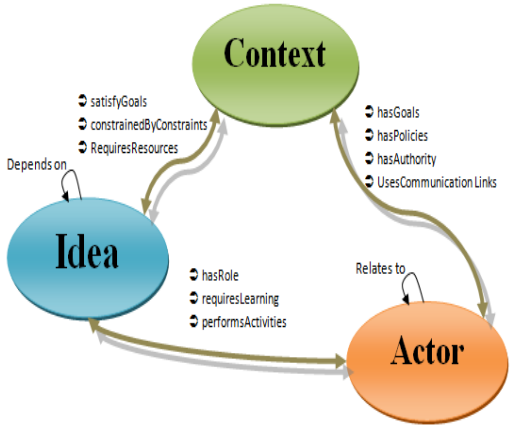

Figure 3. Innovation management ontology main concepts.

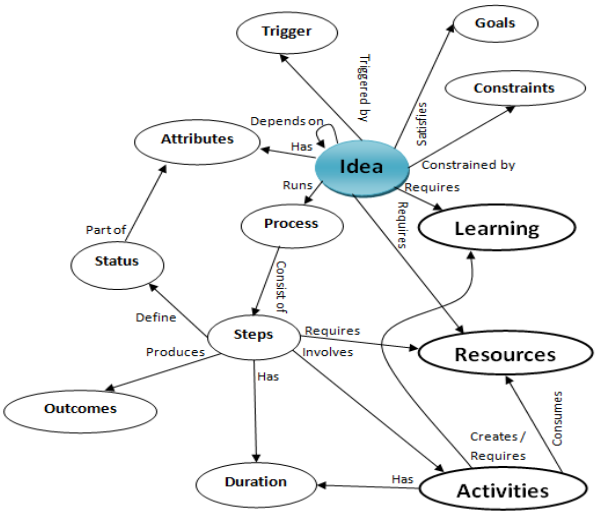

Figure 4. Innovation core -idea- management sub-ontology.

Among this ontology, all the information about innovation management are classified in three categories and specified in three Sub-Ontologies as follows:

- Innovation Core -Idea- Management Sub-Ontology

Innovation Core -Idea- Concept refers to the expenditure of a creative, collaborative and learning effort to achieve one or more organization goals, and which materialize as Idea (Until the validation step), Invention (Until the implementation step) and Innovation (From the exploitation step). Fig. 4 depicts the Innovation Core Sub-Ontology's concepts:

Trigger Concept describes events leading to the idea generation.

Process Concept defines activity networks organized in steps to allow the transformation of an idea into a successful innovation.

Outcomes Concept denotes the results of each step of the innovation management process.

1) Innovation actor management sub-ontology

Innovation Actor Concept describes people interacting within the innovation process and supports the effective management of their involvement, in order to achieve one or more organization goals collaboratively. This Sub-Ontology seeks to allow analyzing personnel characteristics (knowledge, expertise, skills and goals); selecting and hiring qualified people; assigning suitable roles to aid in obtaining appropriately focused teams as needed in each stage of the innovation process; exchanging frequent feedback related to goal attainment and linking between individual/team innovativeness, recognition, rewards and the organization's profitability. Fig. 5 depicts the Innovation Actor Sub-Ontology's concepts:

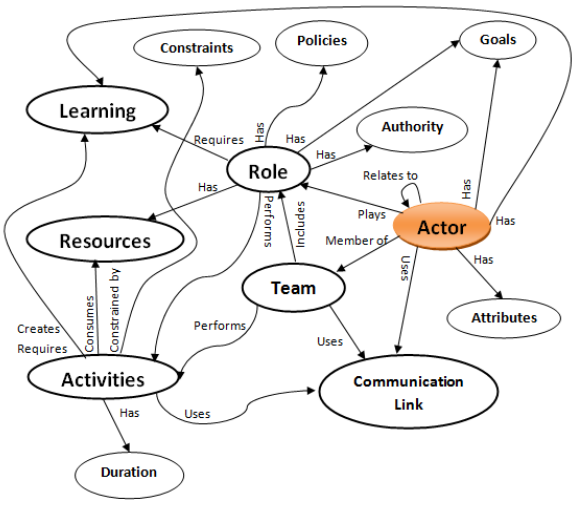

Figure 5. Innovation actor management sub-ontology.

Activities concept describes required actions to be performed by a role to achieve defined objectives of a given step in the innovation process.

Roles concept defines prototypical job functions that an innovation actor may play, alone or within a team, to achieve a set of defined goals, according to the authorities and the policies he has.

Elsewhere, much of the applied literature on the management of innovation has ignored the research by cognitive psychologists and social-psychologists about the effective team building [28], which we consider very important to dig for our research area.

2) Innovation context management sub-ontology

Innovation Context Concept refers to the internal and external contextual factors of organization (e.g. Resource endowments, Customer needs …), the innovation core -idea- contextual factors (e.g. Location, Time…) and the innovation actor contextual factors (e.g. Authorities, Communication Link…). Fig. 6 depicts the Innovation Context Sub-Ontology's concepts:

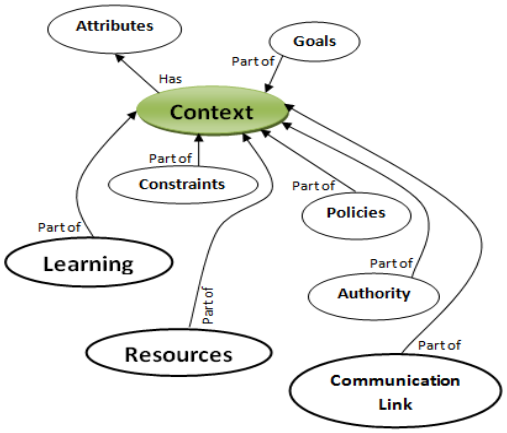

Figure 6. Innovation context management sub-ontology.

Learning concept refers to the flows of activities for acquiring and using new knowledge to bring new ways of thinking, through innovation actors' progress tracking, feedback interpreting and the analysis and provision of knowledge, competencies and skills needed to perform an activity.

Resources concept describes organizational resources to be allocated to a role for disposition under its authority to carry out certain activities. It may also been results of other activities through the innovation process. It seeks to support decision making about assigning the right resources to the right target.

C. Reusing Other Ontologies

TABLE III. REUSED ONTOLOGIES

Ontology	Description
RDF	Resource description Framework
Dublin Core	A set of metadata elements for describing a wide range of resources.
FOAF	Describes people and social relationship on the Web.
SIOC	Describes online communities.
SKOS	Used for knowledge organization systems representation.

Using other ontologies to describe some concepts enables efficient inferencing and reasoning, enrich the ontology and, at the same time, keep it consistent. The most important ontologies reused in the Innovation Management Ontology are summarized in Table III.

D. Ontology Evaluation

In general, an ontology is evaluated on the syntax, structure and semantics of its conceptual definitions. The syntax evaluation is about the formalism used to represent the ontology. The structure evaluation is about the organization of its concepts. The semantic evaluation validates and verifies of the semantic features of an ontology [21].

The list of general criteria suggested by the knowledge engineering researchers are useful for semantic evaluation, but the conceptual definitions in the ontology ought to be semantically consistent with the area of knowledge to be modeled, which is determined by the need and use of the ontology [21]. Annamalai stresses that competency is a consequential quality of a usable ontology that must be present [29]. A competent ontology, espouses adequate ontological commitments to provide for the ontology's purposive mechanisms [21]. To evaluate the competency of an ontology, a set of competency questions is used. The competency questions can be viewed as a form of ontology requirements specification.

Below a set of competency questions we used to verify the Innovation management Ontology regarding its consistency and completeness.

1) Innovation core -idea-competency questions

- What is the event that triggered the idea X?
- Which ideas satisfy the organizational goal T?
- Which status has the idea X?
- Which ideas reached the validation step?
- Which ideas have already been implemented?
- What are the outcomes of the exploitation stage of the invention S?
- Does it have a business plan attached?

2) Innovation actor competency questions

- Which roles can the actor Y play?
- Which roles are required to build an effective team for Idea Improvement?
- Which learning skills the actor Y needs to perform the activity Z?
- Which communication link the actor can use?

3) Innovation context competency questions

- What are the goals of the organization?
- Which resources does actor Y have authority to assign?

VI. CONCLUSION

Both internal capabilities and openness towards knowledge sharing are important for upgrading innovative performance. The innovation process thus can be seen as a continuous interaction between internal and external actors of an organization, around an idea and in a specific context. Understanding the process of innovation is to understand the factors that facilitate and inhibit the development of innovations. All factors refer to three cornerstones we have identified, which are the innovation core –idea-, the innovation actors, and the innovation context. An understanding of how these factors are related leads us to implement a semantic representation

through a common innovation ontology for the purpose of supporting the full defined life cycle for the innovation management and achieving interoperability in an open environment.

In this paper, a generic and new modular Innovation Management Ontology was presented. We perceive this ontology as the foundation for a high-level abstract framework for innovation management that can be integrated into a multitude of contexts. The aim of this framework is to orchestrate collective intelligence and collaborative learning in order to foster innovation. In terms of future work, we plan to experiment our ontology with various methods and continue its improvement to reflect innovation knowledge as best as possible.

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