Leveraging Digital Knowledge Ecosystem Framework Implementation

Case Study: Aligning Knowledge Management and Innovation Goals for Agricultural Aerial Pest Control

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Abstract **- This article proposes a new methodology based on action–research for implementation of a business, system and technology model to assist and facilitate the collaborative use of resources and expertise, as well as to adjust one task force based on knowledge sharing and management. A case study is presented to illustrate the results of implementing the digital knowledge ecosystem framework in a research and development network of aerial application of pesticides for pest control, using the action–research approach. Results include the properties of self-management, open innovation, self-organisation of the institutionally linked groups and the adaptation of a new tool for collaboration, which can improve competitiveness. Its relevance may be measured by its benefits of capturing the sharing dynamics, processing and propagating information within the networks, allowing cooperation between organizations, measuring collective intelligence action and learning, as well as promoting survival such as minimum interaction rules, individual autonomy and organisational structure demand flexibility. Such arrangement proved to allow non-linear methods replacing attempts at objectivity, linear thought and control, and the design of risks in social computing system. The conclusions showed the opportunity to apply such model to other sectors related to agriculture and innovation and observe the challenge regarding to managerial indicators for future command and control of existing r&d network knowledge management operations for future research.**

Keywords: digital knowledge ecosystem, knowledge ecosystem framework, knowledge management, pest control

I. INTRODUCTION

Information and communication technologies (ICTs) have been undergoing a new wave of revolutionary transformation that is based on collaborative and cooperative practices and strategies for knowledge generation, sharing and absorption. Figure 1 depicts the technological evolution of knowledge openness towards more and different types of people-from inside and outside the organisation.

In the context of inter- and intra-organisational relationships of knowledge articulation, management and operations have been moving from a vertical to a hybrid model. However, information technology (IT) continues to be a poor instrument for knowledge communication. After introducing the Internet into the market and shifting business interactions to collaboration and cooperation-based models, IT became more important for knowledge communication. Recently, the World Wide Web and previous web forms (web 1.0 – web 5.0) have created social capital and are considered as a set of current and potential resources linked to the possession of a durable network of more or less institutionalised relationships of mutual knowledge and recognition [1]. Figure 2 shows an overview of the web evolution within business knowledge interactions.

Since 1990, the main challenge of knowledge innovation and communication architectures has been to transform them into a more user-driven, flexible and “open” environment in which new business competitive advantages can be created. In addition, recent challenges indicate the need to identify self-organising groups linked to the institution and to tailor new tools for naturally occurring knowledge collaboration. Rather than hiring professionals specialised in social media or creating web related tools, it is necessary for organisations to understand this new phenomenon of self-organising collaborative processes and group formation.

978-1-5090-0662-5/16 $31.00 © 2016 IEEE
DOI 10.1109/ICSC.2016.81

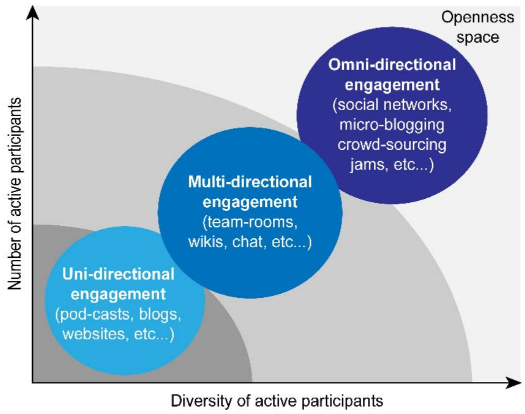

Figure 1 - The evolution of knowledge openness towards more and different types of people - from inside and outside

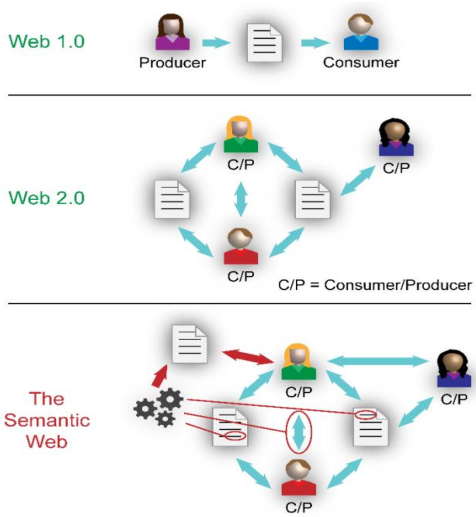

Figure 2 - An overview of web evolution 123

Institutions open to this phenomenon will incorporate an organisational culture and change the view of managers and professionals [2][3][4]. In the context of industrial articulation, management and operations, these challenges have been approached in several industry sectors using six main social business patterns [5][6]: Customer engagement, Recruitment and Integration, Experience and Knowledge and Innovation.

These initiatives highly evolved the complexity of internal and external business innovation environments (systems) and ICT frameworks. The restructuring of the business innovation operations based on the revolutionary open innovation and cooperative-oriented network paradigms have become even more decisive for their survival in an adaptive complex system [2][5][7].

This progress is depicted in an ecosystem concept analogy such that cooperation knowledge networks have been implemented through different means of demand-driven interactions and engagement, balance, domain-clustered and loosely coupled structures, and self-organisation [5][7][8]. In addition, recent trends in innovation in large companies indicate a higher concern for protecting internal intellectual property and, thus, missed opportunities to enable new technologies with more effective collaboration in the vertical and horizontal business model.

Knowledge about many of these challenges has been used by organisational and communication fields to contribute initially to the characterisation and instrumentation of how industries share knowledge of articulation, management and operations efficiently and effectively [3][5][7][9][10][11][12][13][14].

II. THE BRAZILIAN AGRICULTURE SECTOR AND CHALLENGES FOR THE CONTROL OF AGRICULTURAL PESTS

In the context of the Brazilian agribusiness sector, the evolution of productive, social and environmental processes resulted in the need for increased competitiveness in their value production chains, agricultural management, development of new technologies, technological innovation, and intensification and sustainability of agricultural production systems. Therefore, research and innovation networks have been created in Brazil as a collaborative and cooperative strategy to promote innovation, competitiveness and sustainability in the sector, such as the Network of Innovation and Technology Assessment for Agriculture known as RIPA [15], the Research network for the aerial application of pesticides as a strategy for agricultural pest control of national interest (RNAAP) [16], the Network of research, development and innovation on standardisation and quality of irrigation and drainage-REQUAI (CNPq-RETHINKS), the Cooperative Research Network Program, the ANSP Network and the Network of Social Technology, among others.

To better address the dynamics of the networking organisation phenomenon, a primary challenge, knowledge communication, has been undertaken in an attempt to organise better structural and behavioural properties in cooperation between agents in the complex organisational environments. Likewise, Embrapa has faced the same challenges (presented earlier in this article) in joint cooperation, management and operation of innovation research networks involving governmental and private academic institutions, and competency sharing (involving reducing losses, planning and developing the knowledge and productive chains, adding value, ensuring sustainable development and generating wealth) [16].

III. OBJECTIVE

The present work aims to identify critical factors in developing a knowledge management platform framework for sharing the knowledge of articulation, management and operation of agents from a recent research and innovation network, which was conceived of by Embrapa, for the development of the aerial application of pesticides to control agricultural pests.

Based on the case study research methodology under the action-research approach, this work identifies and integrates the main attributes of a knowledge management platform to help RNAAP´s stakeholders share articulation, management and operations knowledge effectively.

IV. KNOWLEDGE MANAGEMENT ARCHITECTURE IN RESEARCH AND INNOVATION NETWORKS

Expectations for R&D collaborators have never been higher. R&D collaborators today must be prepared for a dynamic, global economy—one that calls on people to use data more thoughtfully, think creatively, and work productively in teams. To meet these challenges, it is paramount that R&D collaborators are supported to facilitate personalisation of instruction at scale. Helping to make this a reality is R&D that focuses on innovations in digital knowledge management technologies, next-generation assessments, data platforms, and other practices that empower R&D collaborators to continually adapt instruction to researcher's needs and give them timely, appropriate feedback to improve learning.

In this context, the knowledge management architecture of these network interactions has been evolving along with the market dynamics with foreseen economic, technological and social consequences of enormous impact. For the ICT architecture studies, with respect to knowledge network dynamics, the main challenges reside in the following: [3] [5] [7] [9] [10] [11] [12] [13] [14] [18] [19] [20][21][22][23][24]:

- Knowledge sharing dynamics: the propagation of knowledge within the networks and how these networks process knowledge;
- Cooperation: the network structure, the details of how the individual nodes and connections propagate, receive and process knowledge and how these nodes, connections and network structures change in time in response to these activities.
- Collective Action: a cohesive group that is determined to reach a goal.
- Failure for Free: do many experiments without fear of making mistakes.
- Learning: learning is a valuable resource for the promotion of survival. Measures such as minimum interaction rules, individual autonomy and a flexible organisational structure demand a new perspective in which subjectivity, non-linear methods and understanding replace attempts at objectivity, linear thought and control.
- Design Risks in Social Computing Systems: explore, understand and make design decisions that mitigate or prevent the risks presented on the wicked design space of complex social computing platforms for knowledge management.

Inspired by these challenges, studies on Computational Science have resulted in cellular automation models for the design of artificial adaptive complex systems with computational properties in spatially extensive and decentralised environments [13][22]. As presented earlier, the new web tools have been an example. However, the challenges of self-management, open innovation, self-organisation of the institutionally linked groups and adaptation of new tools for collaboration that occurs naturally continue in the knowledge management ecosystem.

It is observed that the promotion of organisational knowledge communication is challenging and involves changes in paradigms and organisational culture. When considering this trend, it is necessary to follow, without arrest, the technology while utilising this new self-organised dynamic. Responses to these challenges have been compiled in relation to Knowledge Management and Information Science, Design and Process Science and Computational Science - presented in the following sub-sections.

V. DESIGN AND ANALYSIS OF ORGANISATIONAL KNOWLEDGE NETWORKS

The design of business processes led to the following significant points in the design of the inter-relation between knowledge of agents and connections [5][7][25][26][27]:

- Identification, characterisation, operationalisation, prioritisation, and correlation of organisational objectives through levels of satisfaction, origin, stakeholders, function and domain variables; constraints hierarchy of goals; ranking of goals; differences between goals.
- Identification and characterisation of the concepts involved in or related to the implementation of a reference, including the processes that support the rule and that are triggered by it.
- Identification and characterisation of required information.
- Identification and characterisation of a processes hierarchy.
- Structuring of organisational roles and responsibilities.
- Design of information systems for data checking and analysis.

For the purpose of better communication, these main attributes have been represented using a graphical model, which is detailed in an unambiguous manner and consolidates the different perceptions of network inter-relations toward the models of decision-making (including both activity and product-based models) and value added-based models (VBPMN) [5][7][28]. These models have been referenced in organisational modelling for analysis, understanding, development and documentation of a particular organisation [5][7][25][26][27][28]. In addition, these parameters have contributed to the characterisation of a semantic for knowledge sharing on cooperation and collaborative networks, sustainability and management based on Managing as Designing approach [5][7].

VI. ICT ARCHITECTURES FOR ORGANISATIONAL KNOWLEDGE NETWORKS

The knowledge interaction within collaborative networks has been designed through a variety of ICT architectures, such as [8]:

- Client-server architecture: the knowledge communication is centralised and acts as a command and control environment;
- Peer-to-Peer architecture: at any time, each knowledge of agent has a well-defined role, i.e., can only be client or server, but not both;
- Grid architecture: stitches partners together for resource sharing but cannot avoid counter-free riding;
- Web service network: brokers are centralised and service requesters and providers are distributed in a hybrid architecture that does not guarantee trust and quality of service;
- Digital ecosystem: an open community, with no permanent need for centralised or distributed control or for single-role behaviour. A leadership structure may be formed (and dissolved) in response to the dynamic needs of the environment. The Digital Knowledge Ecosystem architecture has integrated different meanings (semantics) to exchange and process messages to coordinate individual behaviour.

The Digital Knowledge Ecosystem architecture has inspired researchers to transcend the traditional, rigorously defined collaborative environments from centralised, distributed or hybrid models into an open, flexible, domain-cluster, demand-driven, interactive knowledge environment.

VII. THE RESEARCH AND INNOVATION NETWORK FOR AERIAL APPLICATION OF PESTICIDES STRATEGY OPERATION

The RNAAP was designed to work towards a strategy for agricultural pest control of national interest and, in this context, considered organising its approach for crops of rice, sugar cane, citrus and soy due to the importance of developing productive chains for food and energy security and meeting demands for competitiveness and sustainability of the Brazilian agriculture sector. This network is a collaboration and cooperation knowledge network that operates through inter- and intra-organisational interactions among knowledge of academic, government and private institutions, including Embrapa´s research centres, to assess and develop methodologies, tools and technologies for the aerial application of pesticides.

Predominantly, the efficiency of spraying and related drifts should be determined. Additionally, methods and tools that improve the efficiency of the application should be identified based on results for better conditions of handling, safety and productivity of crops as well as minimisation of the effect of drift, both in internal and external areas of application. This network comprises Embrapa´s projects portfolio known as Macroprograma 2 (MP2) of Embrapa´s Management System, which must meet demands for competitiveness and sustainability of the Brazilian agriculture sector.

VIII. THE BEHAVIOURAL, SOCIAL AND DIGITAL KNOWLEDGE NETWORK ARCHITECTURE

The agents involved in the research network are Research Centres of Embrapa, SINDAG, agricultural aviation companies, universities, companies, the INCT-SEC/CNPq, ICMC-USP and the MAPA.

The above agents were introduced into the coordination and execution of the network´s strategy. The network´s consolidation is based on the constitution of a Management Committee, Coordinators-Responsibles, Collaborators and knowledge management tools for sharing databases and information, as well as and mainly by consideration of the same experimentation environments for programmed activities. The negotiation procedure used among the agents was initially designed by personal interaction and was later formalised by communication through emails. Additionally, the organisation and execution of meetings required the use of email for initial and personal contact. A hybrid (virtual and non-virtual) form of communication was used to connect the network agents for negotiation, information processing and contract elaboration.

During the phase of designing the network´s project, representatives of Embrapa developed the operational, financial and legal rules that would guide the execution of the project. Representatives of the Management Committee monitored the assignments personally. The articulation and coordination of the network operation involved many political interests and a participative culture for communication. Day-by-day experiences have shown that, generally, the foundation for accomplishing goals is through political actions. In addition, social and economic interests were present in the agents' relationship. All agents presented a strong interest in benefiting science, creating new market opportunities and internationalising Brazilian technologies.

IX. INTERACTION FRAMEWORK

The agents' interaction within the RNAAP has been operated through a variety of knowledge architectures (as presented earlier in this paper): Client-server architecture, Peer-to-Peer architecture, Grid architecture and Web service network. To achieve the objectives of the RNAAP, the integrated execution of six action plans (APs) was used as a strategy for action. Accordingly, programmed activities that complement each other in the operation of the research network were conducted and sought to generate results that determine and predict elements that can add quality and efficiency to the aerial application of pesticides to selected crops, as shown in Figure 3.

These action plans are: Management and Coordination of the Network (AP1); Efficiency of Aerial Application of Pesticides in the Control of Pests (AP2); Evaluation of Pesticide Drift by Conventional Methods (AP3); Environmental Impact Assessment of the Drift with Use of Bioindicators (AP4); Development of Models, Sensors and Instruments for Monitoring and Minimization of the Drift from Aerial Spraying of Pesticides Processes (AP5); and Technology Transfer (AP6).

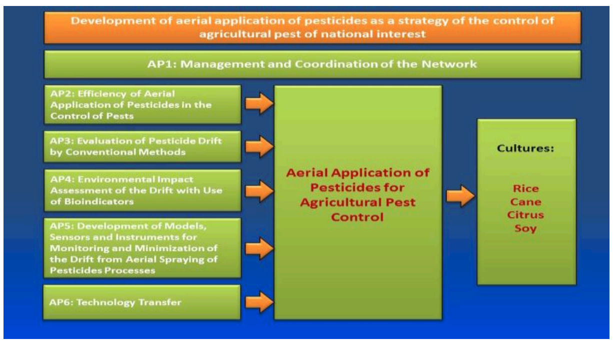

Figure 3 - Organizational knowledge structure of the research network, action plans (APs), focus and cultures of interest

The network´s functions and activities for R&D have been inter-related through the model of decision-making (including activity and product-based models) for analysis, understanding, development and documentation of the project. The function-based form, as shown in Figure 4 (I - FUNCTIONAL), has been used to represent the hierarchy among the knowledge of agents, and the activity-based form, as shown in the same figure (II – ACTIVITY-BASED), has been used to represent the agents' assignments and expected knowledge. The connection among the knowledge of agents is shown in III – RELATIONSHIP NETWORK of Figure 4. Each agent connects to the other according to its knowledge, role and its responsibilities through a hybrid mean of communication and personal interests.

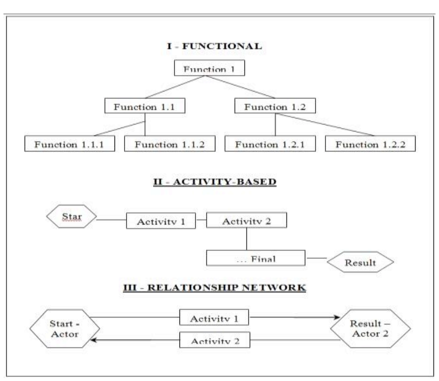

Figure 4 - Knowledge relationship frameworks

Source: Gattaz et al. (2012)

X. RESEARCH PROCESS

The process used to accomplish the objective of this work is action-research based on a unique case study methodology that is conducted using data collection techniques and is supported by literature review. This work involved a strategic and recent research and innovation network of Embrapa that greatly impacts competition of the industry and is responsible for the promotion of its production chains for food and energy security: the RNAAP.

According to Darke et al. (1998) [29], the case study method by means of action-research is characterised by an iterative process that is generalised to theoretical propositions and not to populations and universes. The generalisation to the theoretical proposition is exactly the subject intended by this work, making the case study an ideal instrument to reach the objective.

A detailed semi-structured-questionnaire was created and applied to one of the RNAAP´s research collaborators responsible for the network´s fifth action plan (Development of Models, Sensors and Instruments for Monitoring and Minimization of the Drift from Aerial Spraying of Pesticides Processes) related to the development of six programmed activities to predict the drift minimisation. Additionally, complementary data were collected by observing the execution of the management committee meetings with other research collaborators, totalizing 10 interviewees belonging to the 27 agents that represent significantly the RNAAP, in the period of 2012-2014.

The research purpose was to describe the elements of the inter-organisational knowledge relationship process of the AP5 strategy, which aimed to reduce the gap between knowledge supplies and demands related to a specific high technology, to identify critical knowledge management factors. The reduction of this gap enables many research collaborators to innovate efficiently and effectively in an environment with continued unexpected events. The key questions used in the interviews addressed the following elements discussed in section 3, as exemplified in Figure 5.

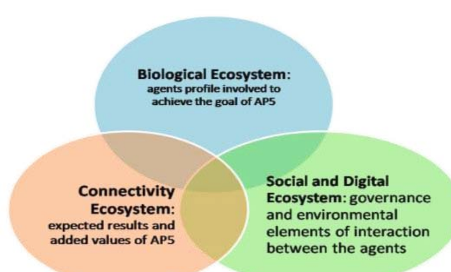

Figure 5: Key questions adopted in the interview

The information obtained through interviews with the research collaborator and its partners were later grouped and organised using a logical structure of networks to redefine the interaction and articulation between all actors.This analysis aimed to guarantee the conditions necessary for AP5 to effectively and efficiently execute its programmed activities for the success of the RNAAP. The information analysis was performed using a keyword cloud tool known as Wordle to combine the keywords of the answers by its weight, resulting in issues that deserve greater knowledge.

XI. FINDINGS AND DISCUSSION

The analysis of the responses resulted in two groups of keywords, considering their respective weights and presentation in the interview, shown in Figures 6 and 7 below.

Figure 6: Grouping keywords that represent the knowledge of greater contact

Figure 7: Grouping keywords that represent the knowledge of less contact

Figure 6 displays the contents of greater contact by the respondent and Figure 7 the contents of minor contact. According to Figure 6, the described semantic parameters of the programmed activities and action plans resulted in a static representation of the RNAAP operations. A big picture of “how” and “why” APs work was described. However, considering Figure 7, the findings encountered from the RNAAP communication process included the following gaps, shown in Table 1, critical for the characterisation of their results of articulation, management and operations:

Table 1 - Gaps in the RNAAP communication process of its results of articulation, management and operations

Biological Ecosystem	Connectivity Ecosystem	Social and Digital Ecosystem
Definition of existing and needed knowledge roles and responsibilities to achieve needed knowledge results and expected added values. Quantitative characterization (e.g. quantity, costs) of the needed roles and responsibilities to achieve needed knowledge and expected added values.	Identification of the network’s objectives and expected added values. Qualitative and quantitative characterization of the network’s objectives and expected added values. Operationalization of the network’s objectives and expected added values. Prioritization of the network’s objectives and expected added values. Correlation of the network’s objectives and expected added values.	Objectification of information. Development of business rules. Decomposition of processes. Design of information systems for data checking and analysis. Formal integration of the ICT architectures into a unique platform. Clarity and completeness in knowledge representation.

The Connectivity gaps have impacted the unfeasibility of the following aspects: i) Synchronisation of knowledge of demands, references and infrastructure (human and technological resources) to meet the network´s objective; ii) Alignment among the agents’ and network´s objectives and knowledge; iii) Conflict management between objectives, knowledge and collateral effects management; iv) Design of knowledge systems aligned to all objectives; v) Qualification and analysis of decisive performance factors of sustainability of collective actions, such as the reduction of waste and value chain costs; vi) Corrections before possible mismatches of essential resources occur; vii) Measurement and analysis of the externalities of collective actions and the integration of the articulation between RNAAP’s strategy (derived from objectives), operations and information technology (actual results).

The Biological, Social and Digital gaps have impacted the semantics modelling for knowledge sharing dynamics, cooperation (creating a sense of group-community of interest), collective action, failures and learning.

Overall, there is a need to approximate the described findings and RNAAP’s interest in choosing and treading a path that permits the optimisation of gains, added value, competitiveness, positioning in the value chain and power of swap as a result of its investments and research efforts and in new undertakings.

These findings require new and critical metrics to model Biological, Connectivity, Social and Digital Knowledge Ecosystems for organisational knowledge communication, development, analysis and decision-making through the identification and management of common objectives, externalities, waste and value chain costs, including the integration of articulation between business strategy, operations and ICT.

XII. LESSONS LEARNED

The variety of ICT architectures to assist and facilitate the collaborative use of resources and expertise, as well as to adjust one task force based on knowledge management, structured informally through different platforms has generated the need to transcend traditional, rigorously defined, collaborative environments from centralised, distributed or hybrid models into an open, flexible, domain-cluster, demand-driven, interactive environment (Digital Knowledge Ecosystem framework implementation).

Using the case study research methodology under the action–research approach proposed in this article to leverage the Digital Knowledge Ecosystem framework implementation can allow research and innovation knowledge network architects to keep a detailed track of the critical factors (aspects) to be carried out for its implementation, improving in this way the project management for the framework implementation.

During the Digital Knowledge Ecosystem framework implementation – in the case study presented, by following the action–research approach proposed, it was possible to clearly define the articulation, management and operations knowledge communication gaps of the network considering the business, system and technological aspects of the Digital Knowledge Ecosystem framework, allowing in this way to the research and innovation knowledge network architects to identify and characterize the missing knowledge during the framework implementation. This represents a significant advantage of the action–research approach proposed from a project management point of view, since the methodology reduces the disturbances in the articulation, management and operations knowledge communication process of a knowledge network during the Digital Knowledge Ecosystem framework implementation and reduces as a result the resources and expertise needed to be allocated for the knowledge network operation.

By leveraging the Digital Knowledge Ecosystem framework implementation using the action–research approach proposed, it was possible to visualise in the case study presented the gaps for aligning the network´s knowledge of articulation, management and operations to the network´s expected added value, allowing the implementation of effective knowledge network structure.

Using the Digital Knowledge Ecosystem framework for aligning the knowledge ecosystem to the business goals of a technology-based knowledge network, allows the research and innovation knowledge network architects and stakeholders to graphically represent the different competencies – and their interrelations – that conform a knowledge network (data, roles, agents, network, time and motivation), offering in this way different viewpoints (scope, business model, system model, technology model and detailed representations), according to each stakeholder's role (planner, owner, designer and builder), to collaboratively define an organisational knowledge structure to improve the network´s business performance and support the network´s business goals achievement.

XIII. CONCLUSIONS AND FURTHER RESEARCH

Digital Knowledge Ecosystem framework implementation is a complex task. Commonly, the DKE framework provides the necessary tools and schemes to organise and document the whole research and innovation knowledge network. Nevertheless, the implementation becomes difficult without an established path to follow or without practical methods about how to develop the DKE. Furthermore, this task becomes more difficult in emerging networks or that base their business' value in technological assets, commonly known as 'technological-based business networks'. This article proposed the implementation of the Digital Knowledge Ecosystem framework combined with an adapted action–research approach in order to assist and facilitate the establishment of the DKE and to provide a practical path of a DKE implementation.

An action–research approach was proposed for carrying out the implementation of the business, system and technological aspects of the Digital Knowledge Ecosystem framework in a technology-based business network. This proposal is composed of a knowledge communication process corresponding to the business, system and technological aspects of the Digital Knowledge Ecosystem framework, and in each aspect, it can be appreciated specific issues that should be carried out respecting the action–research approach.

The knowledge communication process adapts the nature of the action–research approach by modifying continuously the knowledge improvement cycle according to the case study methodology proposed. The improvements can be done n number of times until the expected results are obtained, following the properties of self-management, open innovation, self-organisation of the institutionally linked groups and the adaptation of a new tool for collaboration, which can improve competitiveness.

The result of combining the Digital Knowledge Ecosystem framework with the action–research approach proposed as demonstrated in the RNAAP case study was the identification and integration of the main attributes to obtain the correct and complete information to fill in all the aspects of the Digital Knowledge Ecosystem framework. The action–research approach proposed allows for obtaining a framework that permits visualising the RNAAP DKE in a complete way, to be able to know the scopes, objectives and stakeholders involved and elements that shape the knowledge network.

Further research goes into the direction of the unification of all the Digital Knowledge Ecosystem Framework attributes under existing value based modelling languages (e.g. VBPMN).

XIV. CONTRIBUTIONS TO KNOWLEDGE NETWORK AND KNOWLEDGE COMMUNICATION

Knowledge network (KN) and knowledge communication (KC) aim to enhance the DKE capabilities of a research and innovation knowledge network to become a more agile, flexible and robust in order to achieve both technical and behavioral integration for a greater degree of communication, coordination and cooperation among human actors competencies as well as information systems [43].

Following such integration principles, this article proposed a new methodology based on action–research for the implementation of the business, system and technology aspects of the Digital Knowledge Ecosystem framework to assist and facilitate its implementation as a DKE Framework for emerging-technology-based business networks. The action–research approach proposed may be considered as a novel KN/KC methodology based on a knowledge network modelling strategy that considers technical and behavioral implications thanks to different stakeholders' roles and perspectives provided by the Digital Knowledge Ecosystem framework (e.g. capturing the sharing dynamics, processing and propagating information within the networks, allowing cooperation between organizations, measuring collective intelligence action and learning, as well as promoting survival such as minimum interaction rules, individual autonomy and organisational structure demand flexibility). Authors hope that this research work provides a contribution to knowledge network-modelling-driven approaches for achieving KN and KC.

ACKNOWLEDGMENTS

The authors kindly thank the Research Network for the Development of Aerial Application of Pesticides as Strategy for the Control of Agricultural Pests of National Interest, MP2# 02.11.07.025.00.00, led by Embrapa Instrumentação, for giving the opportunity for this research and Fapesp for financing this opportunity through the process # 201121548-9.

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