The Conception of Organizational Knowledge as a Complex System

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ABSTRACT

In this paper, it is argued that it is necessary a conception of organizational knowledge which is pertinent for seizing the business opportunity created by three national problems of Mexico. Then, diverse disciplinary domains are integrated to conceive organizational knowledge as a complex system of actions in execution displaying the emergent properties of reiterated effectiveness and efficiency in the accomplishment of organizational objectives. Next, the MACOSC-IASC® model which implements this conception is presented as well as two results of using it. The first one, is in the field of open source software development; the second one, is in the Collaboration Fund's tripartite framework (CF) which is being designed to seize the business opportunity. To close this paper, the CF framework's approach to develop the Mexican Industry of Software Development is contrasted with a public policy project named PROSOFT 3.0.

Keywords: Organizational Knowledge, Complex Systems, MSME Productivity, Youth Self-Employment, High Technology Goods Production, Knowledge Management, Open Source Software Engineering.

1. INTRODUCTION

Mexico's trade balance for high technology goods between 2006 and 2012 reported an average negative balance of $15.992 billion USD [19] p. 35. See Figure 1.

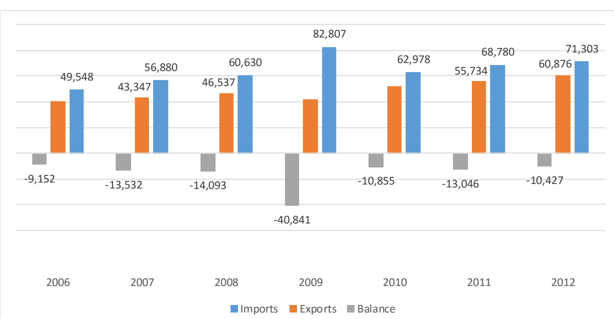

Figure 1 Mexico's Trade Balance for High Tech Goods. Source: Inegi-Conacyt. See [19] p. 35

Aggregated statistical information shows that in 2013 micro, small and medium-sized enterprises (MSMEs) accounted for 99.8% of the country's total formally established companies, employing 71.2% of all salaried personnel, yet, contributing only 35.9% to the GDP, owning only 30.6% of all the productive property, plant, and equipment, and paying less than $25 USD per day to over 21 million people [22], [23]. See Figure 2. In 2012, 35.04% of Mexico's university students with bachelor's degrees in engineering and technology and 45.33% with bachelor's degrees in social science were unemployed [20] pp. 214 and 220. See Figure 3.

Stratum	Economic Units	Employees	Salaries	Contribution to GDP	Fixed Assets
Micro	95.4	39.8	10.1	9.8	9.1
Small	3.6	15.1	12.7	9.5	7.9
Medium	0.8	16.3	18.6	16.6	13.6
Large	0.2	28.8	58.7	64.1	69.4
MSMEs	99.8	71.2	41.4	35.9	30.6

Figure 2 Percentual Productivity of Mexico's Micro, Small and Medium-sized Enterprises (MSMEs) in 2013. Elaborated with data from [22], [23].

	University Students with Degrees	Unemployed	Unemployed %
Engineering and Technology	91,427	32,040	35.04
Social Sciences	198,876	90,148	45.33
All Bachelor's Degrees	406,223	149,897	36.90
Postgraduates (Master's Degrees)	47,798	7,960	16.65

Figure 3 Mexico's University Students with Bachelor's Degrees in 2012 who were Unemployed. Elaborated with data from [20] pp. 214, 220.

In the same vein, Mexico's National Development Plan 2013-2018 acknowledges that it is required the creation of high tech corporations and the promotion of technological innovation and self-employment among the youth who are being educated in the country's higher education institutions [28]. Whilst the OECD, the WEF and others acknowledge that technological innovation and IT may be of help to transversally increase the productivity in a national economy [21] p. iii; [29] p. 18; [30] p. 8; [24] pp. 11, 21; [25] pp. 17-18, 20-22, 31-32; y [26].

These figures represent three seemingly different national problems in Mexico, that of (1) increasing the creation and production of high technology goods and services with high technological content; (2) sustainably increasing the productivity of MSMEs; and, (3) increasing youth self-employment. This paper's research question, in Section 2, interprets these problems as a business opportunity. The hypothesis in Section 3 addresses this business opportunity with the Collaboration Fund (CF), a tripartite technological, entrepreneurial, and financial complex systems framework. The argument, presented in Sections 4 and 5, is that it is necessary a conception of organizational knowledge which is pertinent for seizing such opportunity. A sub-hypothesis to address this need is presented in Section 6. Whilst in Section 7, diverse disciplinary domains are integrated to define organizational knowledge as a complex system. Next, in Section 8, the model and methods for sub-hypothesis and hypothesis testing via the tripartite CF Framework is described. Section 9, presents two results of this applied research project. The first one, is in the field of open source software development; the second one, is in the CF's tripartite framework which is being designed to seize the business opportunity. A discussion which contrasts the CF framework's approach with a public policy project named PROSOFT 3.0 to develop the Mexican Industry of Software Development is presented in Section 10. Section 11 includes additional applied research considered necessary to continue the testing and development of the organizational knowledge conception within the CF framework.

2. RESEARCH QUESTION

Which business model is appropriate for pursuing the vision of sustainably increasing productivity of MSMEs by increasing the production of high technology goods and services with high technological content created in Mexico? How can this model increase youth self-employment and induce MSMEs one step further in the direction of a knowledge economy?

3. HYPOTHESIS

The Collaboration Fund (CF) is a complex systems framework that, for some of the stakeholders, is an appropriate alternative for addressing three apparently different national problems in Mexico, *i.e.*, (1) sustainably increasing the productivity of MSMEs; (2) increasing the creation and production of high technology goods and services; and, (3) increasing youth self-employment. The fund's tripartite framework makes up a business model. The first part of the framework is technological; it uses open source software (OSS) technologies —through a specially designed knowledge management model— aimed at increasing MSMEs' technological assets as common-pool resources. The second part of the framework is entrepreneurial, using a collaborative, research, and business approach for the productivity problems plaguing MSMEs; this includes the creation of very small software development corporations (VSEs) by young entrepreneurial postgraduates and the creation of research and funding entities (RFEs) by seasoned researchers and entrepreneurs. The third part of the framework is financial, tapping into the savings of young entrepreneurial postgraduates, their families, friends, and RFEs as venture capital to initially fund the creation of VSEs. Theoretically, the CF is simulated and calibrated *in silico* as an agent-based model. In practice, the CF is implemented by a distributed and diverse stakeholder network (DDSN) whose vision is to contribute to solve the three national problems and induce MSMEs –and thus Mexico– one step further in the direction of a knowledge economy.

4. OPEN TECHNOLOGIES

To seize the business opportunity, the young entrepreneurial postgraduates require to appropriate the means of production since they require to create, adapt and distribute as needed, *i.e.*, vertically and horizontally, the technological solutions which increase MSMEs' technological assets as common-pool resources. However, this appropriation in the case of closed, proprietary technologies is expensive, even if they were to pay only the annual salaries cost to produce such technologies. As a paradigmatic example, we estimated that salaries software development cost in the range of tens of millions of US dollars per year for the Windows® operating system [5]. Thus, it is clearly prohibitive the appropriation of this type of technology. The alternative is the appropriation of open technologies. However, in the case of open source software technologies, the difficulty to adapt them, when this adaptation requires more than 5,000 lines of code (LOC), limits the young entrepreneurial postgraduates' endeavors. To create such number of LOC is considered the threshold of complexity since it is necessary to involve more than one person in the development of the software. Additionally, in this case the software development team will make an intensive use of organizational knowledge which is considered necessary to be managed to accomplish the objectives of the development [5] pp. 2020-2021, [6] pp. 5-7. However, the dual conception of organizational knowledge is insufficient in this case.

5. THE PREVALENT DUAL CONCEPTION OF ORGANIZATIONAL KNOWLEDGE IS INSUFFICIENT

A new conception of organizational knowledge is required because the dual, prevalent conception [31] that divides it in tacit and explicit is insufficient for the software development team formed by the VSEs that require to adapt open source software technologies as described. See Figure 4, where the upper left corner represents tacit organizational knowledge, *i.e.*, the groups of programmers that created and developed the OSS that is to be adapted. The upper right corner of that Figure represents explicit organizational knowledge, *i.e.*, the documentation of the chosen OSS to be adapted. While the lower central part of the Figure, represents the VSEs that require to adapt the chosen OSS with more than 5,000 LOC and thus require access to the organizational knowledge of such programs.

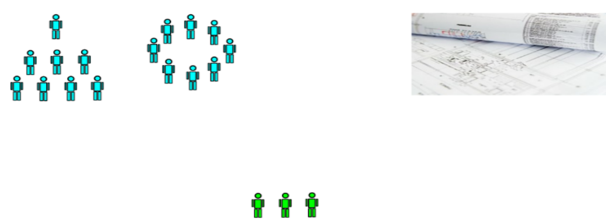

Figure 4 A Representation of the Dual Conception of Organizational Knowledge, Tacit - Explicit, and the VSEs

The tacit organizational knowledge is not available to at least some of those VSEs who decide to adapt the chosen OSS with more than 5,000 LOC. This is so because they cannot bind the groups of programmers that created and developed such OSS for them to help with the adaptation, oriented towards the pursued purpose of sustainable increasing the productivity of the target MSMEs. Along the same line, the explicit organizational knowledge is not available to those VSEs because at least some OSS has not all the documentation required to successfully adapt it as required. These are the conditions where the dual conception of organizational knowledge is thus insufficient for the software development team formed by the VSEs.

6. SUB-HYPOTHESIS

The Technological Part of the Collaboration Fund

The technological part of the CF framework quests for the use and adaptation of OSS by VSEs to sustainably increase MSMEs' productivity via the production of high technology goods and services. This requires a specialized organizational knowledge for software development as well as methods for its management. In Section 4, it was argued why the VSEs require OSS to increase

MSMEs' technological assets as common-pool resources; whilst in Section 5, it was argued why the current dual conception of organizational knowledge is insufficient –as also thus are, in this case, the methods for its management. See [6], [3] for more details. The following conjecture is the first step to fulfill this conceptual insufficiency.

Sub-Hypothesis

The conception of organizational knowledge as a complex system of actions in execution displaying the emergent properties of reiterated effectiveness and efficiency in the accomplishment of organizational objectives is appropriate for those VSEs who require to adapt OSS technologies –through a specially designed knowledge management model– aimed at sustainable increasing MSMEs' productivity via technological assets as common-pool resources.

7. THE CONCEPTION OF ORGANIZATIONAL KNOWLEDGE AS A COMPLEX SYSTEM

Organizational Knowledge

Organizational knowledge is defined as a complex system of actions ***A***, which displays the emergent properties of effectiveness and efficiency to reiteratively accomplish its objectives in a specific domain ***D***, while it is in execution by agent ***X***.

Each action of ***A*** may be a subsystem of actions. The agent ***X*** may be composed by a set of subagents. The conditions {C_{o1}, C_{o2}}, the causal explanations {C_{a1}, C_{a2}, C_{a3}} and the set of variables used for planning {α, ω, σ, τ, ρ, ε, η, χ, δ} as well as the corresponding set of variables used for tracing and measuring {***A***, ***O***, ***S***, ***T***, ***P***, ***E***, ***N***, ***X***, ***D***} are a theoretical representation of the complexity of the system of actions. In those sets: C_{o1} is the required condition of *interdefinibility*. C_{o2} is the required condition of openness. C_{a1}, C_{a2} and C_{a3} are *causal explanations*; α is a representation of the planned system of actions; ω is the set of objectives of the organization established for α; σ is the set of expected results produced by executing α; τ is the time available to accomplish ω; ρ is the set of resources committed to produce σ; ε is the expected set of errors unintentionally produced by executing α that are tolerable; η is the minimum number of times the system α has to be executed to acknowledge that it reiteratively accomplish ω; χ is a representation of the agent; and, δ is a representation of the domain (see Figure 5).

These variables are used to support the definition of organizational knowledge as follows, building thus over the work of Maturana & Varela [38], García [33], Morin [34], and Quintanilla [32] (see [39], [5] and [6] pp. 28-52 for more details).

If an agent ***X*** in a domain ***D***, while executing the system of actions ***A*** in a high degree achieves the objective ***O*** ($\boldsymbol{O} \subseteq \omega$) in time ***T*** ($\boldsymbol{T} \leq \tau$) using resources ***P*** ($\boldsymbol{P} \subseteq \rho$) and gets the desired results ***S*** ($\boldsymbol{S} \subseteq \sigma$) whilst minimizing the unwanted results ***E*** ($\boldsymbol{E} \subseteq \varepsilon$) then ***X*** acts with efficacy and efficiency (wEE) to accomplish ***O*** in ***D***.

If an agent ***X*** executes ***A*** wEE in a domain ***D***, an ***N*** number of times ($1 < \boldsymbol{N} \geq \eta$) then ***X*** acts with reiterated efficacy and efficiency (wREE) to accomplish ***O*** in ***D***. If an agent ***X*** executes ***A*** wREE in a domain ***D***, then the system of actions ***A*** in execution is theoretically considered as organizational knowledge.

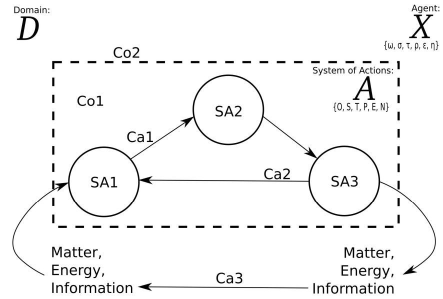

Figure 5 Organizational Knowledge as a Complex System of Actions in Execution

Given the following conditions:

C_{o1} – There is *interdefinibility* among actions belonging to the system ***A***, as well as between ***A*** and ***D***. By *interdefinibility* it is meant that those actions are defined as a function of each other, *i.e.*, each action's execution depends on the execution of one or more related actions of ***A***, as well as defined as a function of ***D***. Such that this condition disappears if we segregate the actions of ***A*** in execution.

C_{o2} – There is openness of ***A*** and its subsystems of actions to the exchange of matter, energy, and information among themselves and with its domain ***D***. This exchange is sustained via the awareness of ***X*** and non-rigid boundaries in ***A*** during its execution by ***X***. Such that this condition disappears if we close such exchange. This also means that ***A*** is necessarily incomplete and plausibly inconsistent at some times during its execution by ***X***.

If the system of actions ***A*** while in execution by an agent ***X*** satisfies the conditions C_{o1} and C_{o2} then ***A*** satisfies the conditions that characterize a system as complex in its theoretical representation α.

Given that by *causal explanation* it is meant that we attribute to the reality of transformations carried out with ***A*** a correspondence with a series of inferences within the elaborated theory that hypothetically defines that α seizes a specific opportunity (see *Diagnose* in Figure 9). If this system of actions ***A*** while in execution by ***X*** transforms reality, in such a way that we accept there is this kind of inferential correspondence for the following three types of causal explanations, C_{a1}, C_{a2}, and C_{a3}, among ***A***'s subsystems of actions and between ***A*** and ***D***:

C_{a1} – Linear causal explanation: such action produces such effect.

C_{a2} – Circular causal explanation: such action stimulates or diminish such effect.

C_{a3} – Retroactive causal explanation: such action produces such effect, which is a necessary cause for the action.

Then ***A*** includes in its theoretical representation, α, the causal explanations that characterize a system as complex.

If an organization, as agent ***X***, while executing the system of actions ***A***, acts wREE to accomplish organizational objectives ***O*** in a domain ***D***; satisfies two conditions C_{o1} and C_{o2}; and transforms reality in such a way that we accept there is inferential correspondence for three types of causal explanations C_{a1}, C_{a2}, and C_{a3} then the system of actions ***A*** in execution is theoretically considered as organizational knowledge and characterized as a complex system [6] pp. 44-45, [39] pp. 78-79.

Emergent Properties of Organizational Knowledge

The reiterated effectiveness and efficiency, under the specified conditions and causal explanations, are regarded as emergent properties of the complex system created during execution of ***A***.

They are emergent properties of organizational knowledge because even if all the actions that compose ***A*** as its subsystems, show reiterated effectiveness and efficiency while executed by subagents of ***X***, this does not imply that ***A***, as a suprasystem, will show reiterated effectiveness and efficiency.

Technological Organizational Knowledge

Organizational knowledge, *i.e.*, the complex systems of actions ***A*** in execution by ***X***, is technological when ***X***, or at least one of the subagents of ***X***, can provide for its theoretical representation, α, causal explanations about why {***A***, ***O***, ***S***, ***T***, ***P***, ***E***, ***N***, ***X***, ***D***} are produced wREE by ***X*** while executing ***A*** in ***D*** to pursue the accomplishment of {α, ω, σ, τ, ρ, ε, η, χ, δ}.

Knowledge Economy

A Knowledge Economy is a complex suprasystem of actions which shows the emergent property of reiterated effectiveness and efficiency to accomplish its objectives via subsystems that recursively display organizational knowledge. It has four key objectives: to trade high technology goods and services; to establish and execute innovation processes; to create and produce innovative high technology goods and services; and, to promote and perform scientific research to support the entire process. Its subsystems integrate in a planned way among themselves via {α, ω, σ, τ, ρ, ε, η, χ, δ} variables; and "in the facts" via {***A***, ***O***, ***S***, ***T***, ***P***, ***E***, ***N***, ***X***, ***D***} variables. See [35] pp. 15, 42 and [36] pp. 16-17 and 45-61 for the definition of technology and innovation.

Knowledge Society

Knowledge Society is a complex suprasystem of actions which shows the emergent property of reiterated effectiveness and efficiency to socially innovate and implement a Knowledge Economy, via subsystems that recursively display organizational knowledge. In a similar way, its subsystems integrate in a planned way among themselves via {α, ω, σ, τ, ρ, ε, η, χ, δ} variables; and "in the facts" via {***A***, ***O***, ***S***, ***T***, ***P***, ***E***, ***N***, ***X***, ***D***} variables. See [37] for the definition of social innovation.

8. THE MODELS AND METHODS FOR SUB-HYPOTHESIS AND HYPOTHESIS TESTING

The Technological Part of the Collaboration Fund

The new conception of organizational knowledge that is hypothetically appropriate for those VSEs who implement the CF to pursue their vision has been presented in Section 7. The knowledge management model which was specifically designed upon this conception to apply and test the sub-hypothesis for open source software development, is presented next. See Figure 6.

The MACOSC-IASC® Model to Test the Sub-Hypothesis

The MACOSC-IASC® model is a theoretical representation, α, of a system of actions that offers a software engineering systemic approach for those VSEs who require to adapt OSS technologies aimed at sustainably increasing MSMEs' productivity via technological assets as common-pool resources. Its design as a framework is intended to guide the fulfillment of the organizational knowledge management need of these VSEs.

The MACOSC part of the Model

MACOSC is an acronym in Spanish meaning: A Model to Manage Organizational Knowledge as a Complex System. It names a part of α that includes three subsystems of actions: *Use*, *Adapt* and *Contribute*. The VSEs execute these subsystems of actions, interwoven with the IASC's four subsystems of actions, for one or more OSS. From the perspective of a plausible causal explanation the chosen OSS is considered useful to sustainably solve the productivity problem of the target MSMEs. The causal explanation comes from a theory created or elected whilst weaving together the IASC's *Diagnose*, with the following *Use* and *Plan* subsets of actions.

1) *Use* Is a subsystem of actions of α where the VSE, as agent χ, pursues as ω: "to run initially on a development platform and eventually on a production platform, the chosen OSS". It is composed of the following subsystems of actions: *Observe*, *Represent*, *Compile*, *Verify*, *Run*, and *Apply*. The description of each subsystem is as follows. 1.1) *Observe* where, in the case of the OSS license, the expected quantifiable result σ is the confirmation to proceed, if and only if, such license allows the usage of the OSS as a commons' technological asset. The OSS code is then downloaded to the development platform and reviewed, the expected quantifiable result σ is an inventory of all the artifacts that compose it. 1.2) *Represent* where the OSS code is processed with tools to generate diverse representations. In this case σ are representations, *ad-hoc* to the cognitive state of the sub-agents of χ, which enhance the usage of the OSS. 1.3) *Compile* where the code is compiled and setup. The expected quantifiable result σ is an executable program, library, or application programming interface (API), which is ready to be run or invocated. 1.4) *Verify* where the executable program, library or API is tested using the code that comes with it or that is written for this purpose, guided by quality and functional requirements to be satisfied by the OSS. The quantifiable expected result σ is a confirmation to proceed, if and only if, the OSS pass the tests. 1.5) *Run* where the executable program, library, or API is run and used in a pre-production platform during a time less or equal to τ. In this case σ is a confirmation to proceed to use the OSS in an application, if and only if, it is considered useful as a commons technological asset. 1.6) *Apply* where one or more applications are developed with the OSS to pursue the fulfillment of financial, quality, functional, social, and ethical requirements for the commons technological asset. The requirements are to be increasingly satisfied and reported as **S**, and the tolerable errors reported as **E**. The cycle *Compile*, *Verify*, *Run* is followed iteratively for each new application developed with the OSS in slots of time less or equal to τ. Once the level of {***A***, ***O***, ***S***, ***T***, ***P***, ***E***, ***N***, ***X***, ***D***} variables are close enough to {α, ω, σ, τ, ρ, ε, η, χ, δ} variables, the application is released to the production platform.

2) *Adapt* Is a subsystem of actions of α where the VSE, as agent χ, after executing at least η times the *Apply* subsystem of actions of *Use* on the chosen OSS, decides to take an opportunity, ω, to change it to increasingly satisfy the requirements associated to the commons technological asset. The *Adapt* subsystem of actions is a superset of *Use* and it is composed of the following subsystems of actions: *Observe*, *Represent*, *Modify*, *Compile*, *Verify*, *Run*, *Apply*. The description of each subsystem is as follows. 2.1) *Observe* where the OSS's code to change is thoroughly reviewed, the expected quantifiable result σ is an inventory of the change's impact. 2.2) *Represent* where the OSS code change is processed with tools to generate diverse representations, σ, *ad-hoc* to the cognitive state of the sub-agents of χ, showing the impact of the change in the OSS. 2.3) *Modify* where the specific areas of code of OSS are changed. The quantifiable expected result σ is a new version of the modified OSS. 2.4) *Compile* where the code is compiled and setup. The expected quantifiable result σ is an executable program, library, or API, which is ready to be run or invocated. 2.5) *Verify* where

the executable program, library, or API is tested using the code that comes with it, as well as with the one that is written to test the specific change and its impact, guided by quality and functional requirements to be satisfied by the modified OSS. The quantifiable expected result σ is a confirmation to proceed, if and only if, the modified OSS pass the tests. 2.6) *Run* where the executable program, library, or API is run and used in a pre-production platform during a time less or equal to τ. In this case σ is a confirmation to proceed to use the modified OSS in an application because it is considered useful as a commons technological asset. 2.7) *Apply* where one or more applications are created with the modified OSS. This is guided, at least, by financial, quality, functional, social, ethical, requirements for the commons technological asset. These requirements are to be increasingly satisfied and reported as **S**, and the tolerable errors reported as **E**. The cycle *Compile*, *Verify*, *Run* is followed iteratively for each new application developed with the modified OSS in slots of time less or equal to τ. Once the level of {***A***, ***O***, ***S***, ***T***, ***P***, ***E***, ***N***, ***X***, ***D***} variables are close enough to {α, ω, σ, τ, ρ, ε, η, χ, δ} variables, the application is released to the production platform.
The *Adapt* subsystem of actions is also executed for any new version of the chosen OSS, released by any external entity contributing to its development, which is considered an appropriate replacement for the current version of the OSS in *Use*.

3) *Contribute* Is a subsystem of actions of α where the VSE pursues as the aim ω: "to deliver a change to the OSS that is considered by the VSE as a valuable addition to the code base of the OSS". It is composed by the following subsystems of actions: *Observe*, *Propose*, *Negotiate*, *Provide*. 3.1) *Observe* is a subsystem where the way and means of interaction of the community developing the OSS are observed and the quantifiable expected result σ is: "a procedure to formulate the change proposal". 3.2) *Propose* where the changes to the OSS are proposed, following the required procedures, to the leader developers of the OSS or its license. 3.3) *Negotiate* where the changes are adjusted to meet any demands of the leader developers. 3.4) *Provide* where the change is sent to the leader developers for its incorporation to the code base of the OSS or made publicly available as specified in its license.

See [5] pp. 2026-2029 and [6] pp. 46-52, for more details.

The IASC part of the Model

IASC is an acronym in Spanish meaning: Action-Research in Complex Systems. It names a part of α that includes four subsystems of actions: *Diagnose*, *Plan*, *Intervene* and *Reflect*. The VSEs execute these four subsystems of actions, interwoven with the just described MACOSC's three subsystems of actions, for one or more OSS.

1) Diagnose Is a system of actions of α where a causal explanation is chosen from a theory because such causal explanation's chain of inferences theoretically match with the description and explanation of the practical problem that keeps the MSME or set of MSMEs in a low productivity attractor. The causal explanation thus starts its development in the *Diagnose* suprasystem of actions described below in the section "The Financial and Entrepreneurial Parts of the Collaboration Fund". *Diagnose* execution is initially interwoven with the execution of the *Use* subset of actions. The aim ω is: "to identify, describe, and causally explain the practical problem that keeps the MSME, or set of MSMEs, in a low productivity attractor".

2) *Plan* Is a system of actions of α where a causal explanation matches with the expected results of executing a designed complex system of action to seize the business opportunity. The aim, ω, is to: "design and establish a system of actions which, integrated with the chosen OSS, hypothetically seizes the business opportunity and solves the practical problems limiting the productivity of the MSME or set of MSMEs".

3) *Intervene* Is the system of actions of α in execution that pursues as a general ω: "to seize the business opportunity and solve the practical problems limiting the low productivity of the MSME or set of MSMEs with the chosen OSS". Once *Intervene* is interwoven with MACOSC's *Use* and *Adapt*, the particular ω pursued is the aim proposed for each of these subsystems during their execution.

4) *Reflect* Is a system of actions where ω is: "to conduct two main evaluations". The first expected result σ_1, is a report of the fitness of the chosen causal explanation. The second one, σ_2, is a report of the fitness of the chosen OSS. Both evaluations allow the VSEs to reflect on the business opportunity and solution to the practical problems from a theoretical and organizational retrospective. This may be interwoven with *Contribute*. These evaluations provide feedback to the financial and entrepreneurial parts of the Collaboration Fund and support the decisions to be made during the next version of α and the next iteration of its execution.

See [1], [5] pp. 2029-2033 and [6] pp. 64-71, for more details.

See Figure 6, for a graphic representation of the MACOSC-IASC® model's instrument used to plan, trace and measure ***A***'s execution as the interwoven subsystems of actions of both, MACOSC and IASC. The instrumentation and implementation of the model helps to test α as well as the appropriateness of the organizational knowledge concept defined in Section 7.

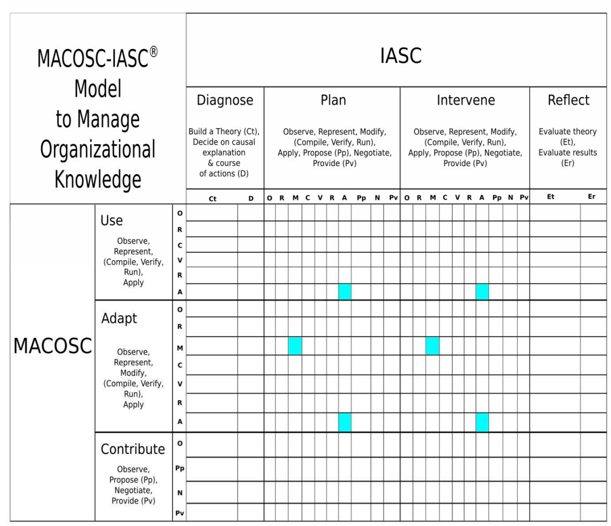

Figure 6 The MACOSC-IASC® Knowledge Management Model

As the VSEs mature in the execution of the interwoven subsystems of actions of both, MACOSC and IASC, they are developing and enhancing those systems of actions, i.e., their organizational knowledge. Several parts of this organizational knowledge theoretically fall into the disciplinary domain of software engineering. The MACOSC-IASC® model thus integrates an adaptation of KUALI-BEH Kernel Extension to be used whilst weaving together the *Use*, *Adapt* and *Intervene* subsystems of actions, specifically during the *Apply* and *Modify* subsystems, for the chosen OSS. This adaptation of KUALI-BEH allows the VSEs to flesh-out the Essence Kernel and Language for Software Engineering Methods during their endeavors. This is indicated in the cyan rectangles in Figure 6. See [3] for more details. See Figure 7, for the MACOSC-IASC's adaptation of KUALI-BEH used to launch the repository of methods and practices as causal explanations, oriented to theoretically support the technological organizational knowledge of at least one of the subagents of the VSE who adapts the OSS (see [5] pp. 2034-2035, [6] pp. 91-104, for more details).

[document Id]	MSMEs Target Organization(s)	
[MSMEs Organization's Name or Id]		
Domain: D		
[current domain's description for the software project]		
[project Id]	Software Project [project's name]	
StakeHolders: VSEs, RFEs, MSMEs [list of stakeholders]		
Work Team: X [list of practitioners, as sub-agents of X, each belonging to one of the stakeholders]		
Start Date ti: T = (tf - ti) [start date of the project]	Finish Date tf: T = (tf – ti) [finish date of the project]	
Resources: P	Errors: E	Iteration: N
[resources for the project]	[errors tolerated in the project]	[iteration index for this type of project]
Objectives: O [project's objectives]	Results: R [project's results]	
[system Id]	System of Actions: A [name and description of the system of actions (which include software engineering methods)]	
Method of Software Development [method selected as a subsystem of A, each method is a set of practices]		
Causal Explanations [At least one of the subagents of X is able to provide causal explanations about why {O, S, T, P, E, N} are produced wREE by X while executing A in D]		

Figure 7 The MACOSC-IASC® adaptation of KUALI-BEH

The Financial and Entrepreneurial Parts of the Collaboration Fund

The financial and entrepreneurial parts of the CF framework are theoretically based on two types of Complex Adaptive Systems (CAS) —VSE and RFE— which address the business opportunity. The first is a Very Small Entity (VSE) for software development [2], with a business model appropriately adapted to sustainably increase productivity in the specific circumstance of each intervened MSME. The second is also a small entity with a venture capital business model for research and funding (RFE), which provides guidance to and funds for young entrepreneurial postgraduates to launch their own VSE as a limited liability stock corporations (SAPI) protecting the rights of minority shareholders (this takes advantage of legislation that has recently been passed by the Mexican Congress which permits the creation of such entities [42]). Every VSE CAS applies the technological part of the framework and includes the following interdisciplinary roles to be assumed by at least two, preferable three, separate postgraduates: i) technology design & development; ii) MSMEs' sustainable productivity applied research; and, iii) organizational management [4]. Every RFE CAS includes, as stockholding investors, seasoned entrepreneurs and expert researchers on the issue of MSMEs' low productivity. Thus, one of the aims of VSE and RFE CAS is to create a business of sustainably increasing MSMEs' productivity [4] (see Figure 8).

VSE and RFE Complex Adaptive Systems (CAS)

The CF framework as a business model establishes a vision for 2038, which is addressing three seemingly different national problems in Mexico, as described in the hypothesis. To induce MSMEs one step further within a knowledge economy, the framework should be comprised of a set of VSE and RFE corporations implemented by some of the stakeholders, theoretically considered as complex systems: $\varphi_{1..n}(i,a,\psi)$ and $\Phi_{1..m}(I,A,\Psi)$, organized to intervene in specific MSMEs [4]. It is clearly assumed in the main hypothesis, via the existential quantifier, that not all the stakeholders from society, academia, industry and government sectors will be interested or able to implement the CF Framework's distributed and diverse stakeholder network (DDSN). One RFE $\Phi_y(I,A,\Psi)$ works with one or more VSEs $\varphi_x(i,a,\psi)$, where, respectively, i and I are the roles assumed by its agents; a and A are subsystems of the systems of actions α to be executed by its agents; ψ is the productivity of one or a set of the MSMEs to be intervened by the VSE φ_x supported by the RFE Φ_y; Ψ is the productivity of all the MSMEs to be intervened.

Most of the quantitative and qualitative measurements expected if the implementation of the CF framework, as a DDSN, successfully contributes to sustainably increase the productivity of MSMEs, generate youth self-employment and promote production of high technology goods with high technological content created in Mexico are to be based on internationally accepted metrics: Mexico's productivity, competitiveness and R&D expenditures. As a reference, Mexico's position in OEDC gross domestic expenditure on R&D (GERD) was 0.426% of GDP in 2013, equivalent to 6.442 billion USD (at 2005 constant dollars and purchasing power parity), with less than one researcher per thousand employees in the formal economy [7], [4].

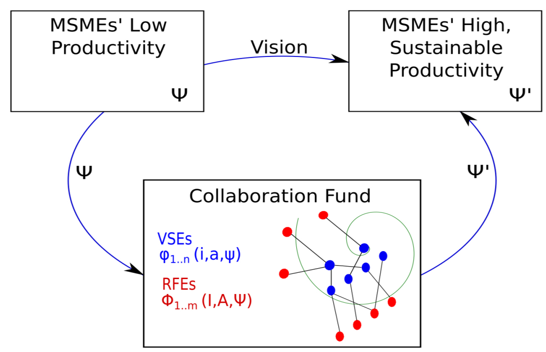

Figure 8 The Collaboration Fund: A Distributed Diverse Stakeholder Network formed by VSEs and RFEs Complex Adaptive Systems

Method to Test the Hypothesis of the Collaboration Fund Using the MACOSC-IASC® Model

The MACOSC-IASC® model is also used to test the hypothesis for the financial and entrepreneurial portions of the CF framework via increasingly rigorous experiments to address several of Mexico's main economic issues as a business opportunity. The use of this model is part of the theoretical systems of actions, α, for VSE φ_x and RFE Φ_y, a and A respectively. Thus, the VSE $\varphi_x(i,a,\psi)$ and RFE $\Phi_y(I,A,\Psi)$ CAS, execute the three MACOSC subsystems of actions interwoven with the IASC's four subsystems of actions, for one or more scientific theories. From the perspective of a scientific theory the chosen plausible causal explanation is considered useful in the quest to sustainably solve the productivity problem of the target MSMEs. The causal explanation is built from a theory created or elected by the young entrepreneurial postgraduates before launching their own VSE. First, they —while studying to earn their degree— become aware of a practical productivity problem of a MSME or set of MSMEs (See [40], [41], and [6] pp. 104-110). Once they earn their degree, they may and decide they want to address the theoretically solved problem as a business opportunity. Then, they assume their interdisciplinary roles and, in collaboration with a researcher of an RFE, use their theory as a starting scientific approach for their endeavors. Once the VSE is created, they follow the MACOSC-IASC® model:

1) *Use* Is a subsystem of actions of *a* where the VSE, as agent χ, pursues as ω: "to use at least one causal explanation that support the solution of the productivity problem faced by one or more target MSMEs". *Use* has the following subsystems of actions: 1.1) *Observe* where the expected quantifiable result σ is a theoretical description of the productivity problem and its solution. 1.2) *Represent* where the VSE construct the *objet d'étude*. In this case σ are representations, *ad-hoc* to the cognitive state of the sub-agents of χ. 1.3) *Apply* where one or more causal explanations are created, guided by financial, sustainability, social, ethical, requirements to solve the productivity problems of the MSMEs. In this case, there is at least one causal explanation that theoretically supports the VSE's endeavor to solve the problem as a business opportunity.

2) *Adapt* Is a subsystem of actions of *a* where the VSE, as agent χ, after executing at least η times the *Apply* subsystem of actions of *Use* on the chosen theoretical perspective, decides to take an opportunity to change the theory to create sound causal explanations. The *Adapt* subsystem of actions is composed by: *Observe*, *Represent*, *Modify*, *Apply*. 2.1) *Observe* where the expected quantifiable result σ is a new causal explanation associated to the description of the productivity problem. 2.2) *Represent* where the VSE construct a refined *objet d'étude*. In this case σ are new theoretical representations, *ad-hoc* to the cognitive state of the sub-agents of χ. 2.3) *Modify* where the specific areas of the chosen theory are changed. The quantifiable expected result σ is a new theory that supports the construction of a refined *objet d'étude*. 2.4) *Apply* where one or more causal explanations are created, guided by financial, sustainability, social, ethical, requirements to solve the productivity problems of the MSMEs. Thus, to execute *Adapt*, the VSE starts again in the research mode, proceeds to modify the theory, and then follows the execution of its subsystems of actions, until being able to generate a new sound causal explanation and a refined *objet d'étude* for the productivity problem of the MSMEs.

3) *Contribute* Is a subsystem of actions of *a* where the VSE pursues as the aim ω: "to publish a paper describing the change to the theory that is considered by the VSE as a valuable addition to the scientific works around it". It is composed by the following subsystems of actions: *Observe*, *Propose*, *Negotiate*, *Provide*. 3.1) *Observe* is a subsystem where the way and means of interaction of the community developing the theory are observed and the quantifiable expected result σ is: "a procedure to formulate the theoretical change proposal in a paper". 3.2) *Propose* where the changes to the theory are sent to the reviewers as a paper, following the required procedures. 3.3) *Negotiate* where the changes are adjusted to meet any demands of the editor or reviewers of the paper. 3.4) *Provide* where the paper is sent to the editor for its publication.

See [5] pp. 2026-2029, [6] pp. 46-52, [43], and [44] for more details.

The MACOSC's three subsystems of actions, *Use*, *Adapt*, and *Contribute*, are interwoven with the following IASC's four subsystems of actions *Diagnose*, *Plan*, *Intervene*, *Reflect* (see Figure 9):

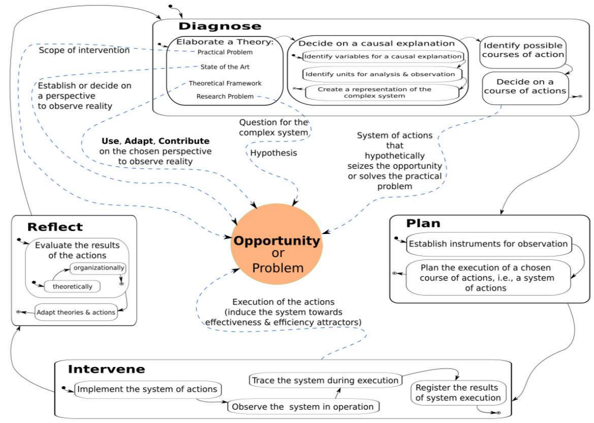

Figure 9 Complex Systems Action Research Methodology

1) *Diagnose* Is a system of actions where one or more theories are used or created using quantitative and qualitative perspectives by the stakeholders participating in $\varphi_X(i,a,\psi)$ and $\Phi_Y(I,A,\Psi)$ CAS to identify measurable aspects of the empiric complex. This empiric complex is the MSMEs' productive reality to be intervened, and the measurements are expressed recursively using the set of variables {***A***, ***O***, ***S***, ***T***, ***P***, ***E***, ***N***, ***X***, ***D***}. There are two main aims of this system of actions. The first one is to iteratively construct a causal explanation of the MSME's current system of actions and associated low productivity ψ. The second aim, is to iteratively construct a causal explanation, by the young entrepreneurial postgraduates, to support the design of a system of actions *a* to intervene the MSME and which is considered necessary to induce a change in its current productivity ψ to a higher sustainable productivity ψ'. The later system of actions supports the VSE's endeavors during the implementation of a solution in the technological part of the CF.

2) *Plan* Is a system of actions where the VSEs' aim, ω, is to create the plan to induce a change in MSMEs current productivity ψ to a higher sustainable productivity ψ' during the intervention with the designed and chosen system of actions *a*. It is required to express *a* as a business plan. The main target metrics are established in the set of variables {α, ω, σ, τ, ρ, ε, η, χ, δ}. In this plan, the details of how to observe and measure these in the empiric complex during the intervention in the MSME are established. The business plan of the young entrepreneurial postgraduates as stakeholders participating in φ_X is supported and validated by seasoned entrepreneurs and researchers, as the stakeholders conforming Φ_Y.

3) *Intervene* Is a system of actions where the business plan is carried out during the intervention in the MSME to induce a change in its productivity from ψ to ψ'. The main metrics are observed and registered as the set of variables {***A***, ***O***, ***S***, ***T***, ***P***, ***E***, ***N***, ***X***, ***D***} during the execution of the set of actions *a* supported by *A*.

4) *Reflect* After intervention in the MSME, there are two main evaluations in this system of actions. First, from a scientific perspective the theory used to support the system of actions that are required to induce a change in MSMEs' productivity from ψ to ψ' is evaluated, using the set of variables {α, ω, σ, τ, ρ, ε, η, χ,

$\delta\}$ and $\{\boldsymbol{A}, \boldsymbol{O}, \boldsymbol{S}, \boldsymbol{T}, \boldsymbol{P}, \boldsymbol{E}, \boldsymbol{N}, \boldsymbol{X}, \boldsymbol{D}\}$: the scientific knowledge of both φ_x and Φ_y CAS, represented in (i, a) and (I, A) about the empiric complex, ψ and Ψ, must be more effective and efficient. This organizational knowledge is expressed as an effective theoretical refinement of the number, kinds and relationships of the variables used. It is also expressed by the techniques, technologies and organizational practices used during the intervention in the MSME. The second evaluation is made from an organizational perspective. This includes: the financial statements, both pre and post intervention, for each of the financially involved stakeholders; the confirmation of the sustainability of the new production process; and the confirmation that organizational knowledge was developed by the MSME during the intervention.

9. RESEARCH RESULTS

The Collaboration Fund's vision aims to sustainably increase the productivity of MSMEs; increase the creation and production of high technology goods and services with high technological content; and, increase youth self-employment in Mexico. There are two main results of pursuing the vision for this complex systems action research project. First, a successful initial test of the MACOSC-IASC® knowledge management model [1], [6]. The test allowed to create a technological solution to increase the sustainable productivity of a MSME with OSS. The technological solution was a high-performance CORBA® server to process events (see Figure 10). Second, the business model's intangible assets which fulfill the initial CF framework requirements have been delivered by an interdisciplinary team and approved by the National Council of Science and Technology (Conacyt)-Secretary of Economy's Innovation Fund (FINNOVA) by the end of 2015.

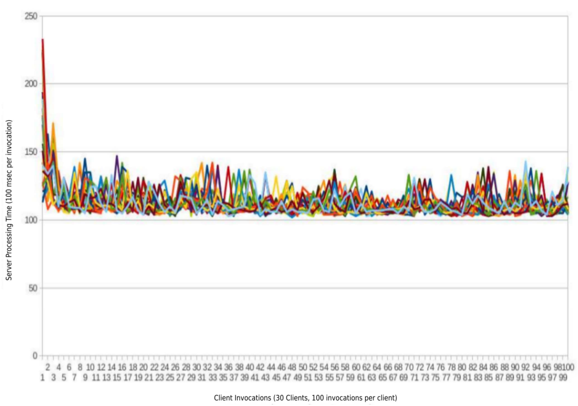

Figure 10 Behaviour of a High-Performance CORBA® Server Developed with OSS.

10. DISCUSSION

Several of the OECD member countries considered to have successfully implemented a knowledge economy reported a five to ten times larger GERD than Mexico in 2011 [7]. The US's GERD was 2.806% in 2013, equivalent to 396.711 billion USD (at 2005 PPP). The contribution to this investment in 2011 was: 60.0% by corporations, 33.4% by the government and 6.6% by academic institutions, non-lucrative and external sources. Other OECD members, notably South Korea and Israel, have a highly differentiated percentual contribution to their GERD [7]. Most of the corporations from these countries strongly pursue the protection of their intellectual property. On average, 97.07% of all granted patent filings in Mexico between 1993 and 2015 were for those corporations. See Figure 11, prepared with data from [27]. Thus, one venue to explore is identifying which venture capital practices of these countries and their corporations are applicable to the development of a CF framework in the context of the Mexican Industry of Software Development (MISD).

Additionally, to approach the conception of organizational knowledge from a complex systems theoretical perspective allows for exploration of the systems of actions in execution, carried out by the agents participating in the MISD at the levels of sub, mezzo and supra systems. This approach also facilitates the research and development of non-reductionist solutions to the problems it faces. This approach is thus being used to propose the development of the CF framework to strengthen the MISD by also opening the door to the development of an internal market for software technologies to be consumed by MSMEs. The CF endeavor is to increase the technological assets of the MSMEs as common-pool resources [13], [14]. In contrast, PROSOFT 3.0 – the public policy project [24], [25], [26] to develop information technologies in Mexico between 2014 and 2024– has presented us, as participants of the MISD, an eight-route map [16] to pursue five main objectives. Each route solves a problem being faced by the MISD. However, in those problems quality has consistently been identified as the key desired effect required to attain the proposed objectives.

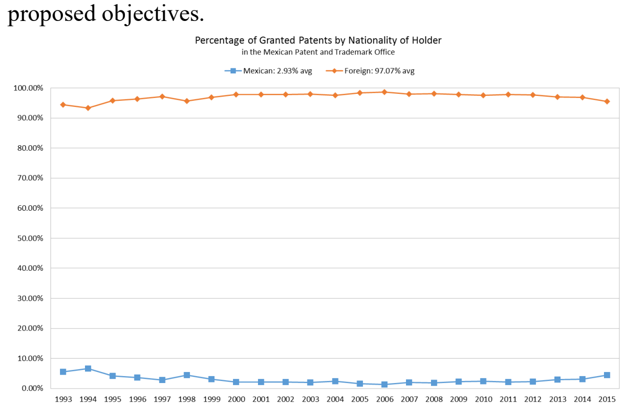

Figure 11 Percentage of Granted Patents by Nationality of Holder in the Mexican Patent and Trademark Office (IMPI) between January 1993 and December 2015

PROSOFT 3.0 Main Objectives for 2024 in Mexico

1) To establish one thousand Supreme Quality Centers for Software Development (SQCSD) in the country;
2) To become the second worldwide exporter of software and the third destiny for IT "outsourcing";
3) To multiply the market for IT four-fold;
4) To form five global software development poles in the country;
5) To cover 90% of the demand of software development knowledge workers required by MISD.

To achieve these goals, PROSOFT 3.0 has chosen as the main single cause the implementation –in each SQCSD– of a software engineering development process like CMMI®, TSP or MoProSoft while the high quality of the software developed by SQCSDs would be the principal desired effect to be generated. Figure 12 shows the contrast between the approaches of the CF framework and PROSOFT 3.0.

Finally, to pursue the objective of creating 1,000 SQCSD to develop the MISD without considering the required complexity of the intervention model [17] opens the door to the replication of the situation which the Mexican economy faced in 2013: 1,000 corporations which contributed 56% of GDP hired only 8.5% of all employees, paid 27.4% of all wages and represented but 0.02% of all the corporations in Mexico [18], [22], [23].

11. FUTURE WORK

Necessary research to continue the testing and development of the organizational knowledge conception for the CF framework is projected within interdisciplinary environments and interactions with the intention of: characterizing the required resilience profile of young entrepreneurial students [8]; defining adaptive systemic policy instruments required to foster heterogeneous collaborative capacities in the CF framework CAS and the MSMEs [9]; developing agent-based models for carrying out Complexity Economics experiments *in silico* about the CF's dynamic, distributed and diverse stakeholder network of CAS [10], [11], [12] (also see LaborSim in http://oguerr.com/laborsim/ and http://www.css.gmu.edu/~axtell/Rob/Research/Research.html, and [14] for an account of and reflections on the practical application of this type of models); developing a CF website and exploring the case method [14], [15].

	Collaboration Fund Framework	PROSOFT 3.0
Conception of Organizational Knowledge	A Complex System of Actions in Execution	A Duality: Tacit and Explicit
Intervention Model	Complex, Open, Distributed, Self-organized, Systemic	Reductionist, Closed, Centralized, Hierarchical, Systematic
State of the Intervention	Hypothesis Development	Implemented and in Evolution
Software Engineering Methods	MACOSC-IASC® KUALI-BEH Essence	CMMI®, TSP, MoProSoft, ISO/IEC 29110
Main Target Market	Internal: MSMEs	External: Large Global Corporations
Key Objective	A distributed and diverse stakeholder network of RFEs and VSEs who make a business of developing High Tech Assets as Public Common-Pool Resources	1,000 Supreme Quality Centers for Software Development who make a business of developing Private High Tech Assets
Funding	Private, Society, Academia, and Public	Public, Private

Figure 12 The Collaboration Fund Framework compared with PROSOFT 3.0

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