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***Abstract*—In modern times, Knowledge Management (KM) is seen to be a key instrument in developing organizational competitiveness, especially in the context of dynamic organizations, such as knowledge-based firms. In this paper, we assume that firms are capable of developing dynamic functionality through their own initiative; this means that they are able to change and adapt, becoming agile to their surrounding environment. We propose that an approach from complexity theory may explain the phenomena that arises in an organization as it faces turbulent environments for competence. We introduce the importance of complexity approaches to knowledge management. The key questions addressed in this paper are: (1) How is KM managed through complexity theory, ensuring competitiveness is increased? and (2) How does the approach to complexity theory increase the understanding of competitiveness? This research analyses KM tools to implement management systems, based on knowledge and complexity theory. Although competitiveness is perceived as vital for organizations, the approximation of knowledge and complex theory are not yet fully developed and integrated into organizational processes to increase it.**

Keywords—Complexity Theory, Dynamic Capabilities, Knowledge Management, Organizational Competitiveness.

I. Introduction

As time progresses, organizations must improve their performance in order to survive and increase their influence in the region they operate in. This raises several points. Firstly, we must acknowledge that, on an every-day basis, competition between firms is inevitable and the tasks that one firm has to learn and develop against another places enormous pressure on its strategies and forces the firm to try to understand the relationships developed inside its own organizational structure. Secondly, the complexity in interrelations between agents involved in the firm's operations increases overtime. Customers and suppliers become a strategic asset to their competitive environment and are seen as a key part of the dynamic interaction in the industrial ecosystem where the firm is located. On the other hand, a firm must develop a strategy to overcome challenges and the rivalry of competitors. Under such conditions, KM is one strategy that helps firms achieve competitive market goals. This includes:

- Satisfying existing customers and attracting new ones;
- Improving productivity and the quality of products, services and processes;
- Developing new products and services, based on innovation as a key factor; and
- Developing skills, motivation and teamwork, among employees and stakeholders.

To perform these goals, KM must become part of a firm's policies but, also, it must include an analysis of the organization's environment, including marketplace turbulence and cultural capabilities. This means that the complexity involved in the KM implementation affects the competitive response to the environment and reflects the success of strategies and tactics developed to be successful.

Under this circumstance, this paper goal is to analyze the correlation between three fundamental concepts: (1) Knowledge Management (KM), (2) Competitiveness (Cm), and (3) Complexity (Cx), from a theoretical approach and using data collected in firms in Tijuana(Mexico) and in San Diego (United States) to research validation.

II. Related Work

In this section, we discussed KM, Cm and Cx. In each of these fields, a large amount of research has been conducted, but we propose an approach that correlates the three of them and generates a novel point of analysis with the aim of providing a more holistic approach to the phenomena of firm competitiveness in turbulent environments, this approach has been used in similar studies about organizational learning [1].

A. Knowledge Management

Knowledge management comprises strategies, practices and tools that are used by an organization to identify, create, represent, distribute and enable adoption of insights and experiences as part of a firm's knowledge. Such insights and experiences are considered embodied knowledge in the minds of the individuals (tacit) or embedded in the

organization's processes or practices (explicit). The idea of these actions is to generate new knowledge from each member of the organization and to transfer best practices and techniques to every individual, allowing the increase of intelligence throughout the organization (collective intelligence) [2].

KM has been an established discipline since the last decade of the 20th century. It has been widely researched by scholars and practitioners in fields including: business administration, information systems, information sciences, engineering, biology, health sciences and a lot of other science disciplines.

Large organizations and non-for-profits have created resources that are dedicated to internal KM implementation, often implemented as part of their strategies to increase productivity and improve and enhance results in their respective industries. Most of these attempts are carried out by the 'Information Technology' or 'Human Resources' departments [3]. KM efforts typically focus on organizational objectives, such as improving performance, competitive advantage, innovation, the sharing of lessons learned, integration and continuous improvement of the organization, improvement of leadership and increasing market share and diversity.

Companies also try to empower employees and implement a culture of innovation through KM efforts. There are several challenges that KM is able to help prevent and improve. For example, in Small and Medium Enterprises (SMEs), it is common to experience the following challenges:

- Dependency on a select group of people, such as the founder or the owner. In this example, KM helps to manage the knowledge and prevent the absence of key members in the firm by systematically transferring knowledge to other members of the organization;
- Family culture and its influence on the firm's growth and development. KM is able to maintain, store and recommend actions that improve results;
- Lower degree of formalization of strategies, structures and processes. KM systems can be used as a method to evaluate and determine if any of these components are able to achieve its goals;
- Personalized relations with customers. KM, as a tool, can be used to develop strategies to increase impact on interactions between agents present in the firm; and
- Reduced capacity to process information, generate knowledge and use technology. KM is able to generate, transfer and manage knowledge so that an SME is able to adapt, according to the environment.

Under this review, it is evident that KM has become a strategy required by firms. It does not matter if the company is large, medium or small, the environment is almost certainly turbulent, and this means that changes occur frequently and, if the firm is located in a knowledge-based sector, this change occurs even faster. For this reason, KM is an area of important study and companies must have a better understanding of its use and develop it in practice within the organization [4].

B. Competitiveness

Competitiveness refers to the ability of a firm, sector or industry to produce services or goods with specific quality patterns. To do so, it must use a limited set of resources more efficiently [5] and must design strategies and methods to increase their ability to enhance and improve socio-economic results. There are several concepts and approaches that are deemed appropriate to study and analyze in terms of competitiveness; these include: Competitive advantage; Productivity; Comparative advantage; Resources and sustained advantage; Model of 5 forces of Competition; and Systemic competitiveness.

In a study carried out at the German Institute for Development, Esser et al. [6] determined that industry must be subject to the analysis of its competitiveness from 4 economic and social levels, that are based on social environment and, therefore, systemic. These are:

- **Micro Level:** refers to existing firms and the networks formed between them to improve productive processes;
- **Meso Level:** refers to social agents that interact with the firm. It includes public policy implemented to support and improve collaboration and encourage the formation of structures and alliances between firms;
- **Macro Level:** refers to environmental and social demands that surround companies and imposes levels of performance and productivity. It also refers to government policy at a national level; and
- **Meta Level:** refers to the structure of society, with the aim of detecting organizational patterns in legal, political, economic and social responsibility with a view to strategic integration.

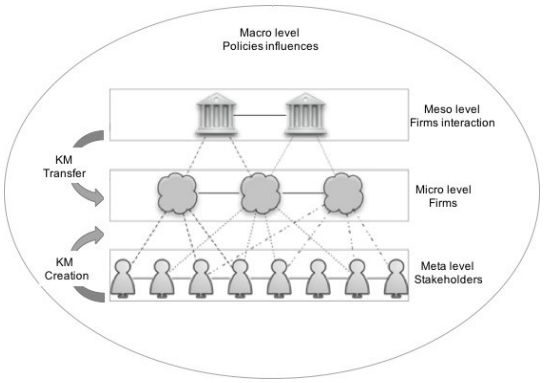

Fig. 1. Knowledge and Competitiveness Interaction

In figure 1 we can see how the 4 levels of analysis are able to influence the competitiveness characteristics of a firm. The figure selects a set of attributes for each level but, there are several others, creating more complex and profound analysis requirements.

In figure 1, it is explained the root of knowledge between Cm levels. This means that people are the creators of knowledge as is shown in the meta level, then the firm uses and implement strategies to make knowledge profitable in the micro level. We also indicate the major transfer from firm's interaction to internal firm actions (meso to micro level), there's also KM transfer between firm's interaction (at a meso level) and then inside firm's departments (at a micro level). All of these actions are determined by the macro level, which is outside the firm influence and is mostly depending on the government and the socio-economic environment in which the firm is operating.

C. Complexity

According to Johnson [7], the "*Science of Complexity*" can be described as "the study of the phenomena that emerges from a collection of objects that interact with each other" and with their environment. Scientists from different disciplines began to analyse natural and social phenomena that met the description of this concept. The 'science of complexity' or the 'applications of complexity' theories contribute to the recognition that every society evolves and there are no easy problems to solve. There are, in fact, only complex problems. The challenge posed by these theories is to ask the right questions and seek the right approaches that are closest to reality of a social, economic and / or political phenomenon.

Hence, the emergence of new institutions, such as the "Santa Fe Institute" (www.santafe.edu) or the "Institute for New Economic Thinking" (ineteconomics.org), which have emerged and are in constant engagement with more comprehensive analysis of the social, computational, economic and management challenges, from a complexity approach. There are four predominant characteristics that define a complex system, and these are discussed as followed, in sections D-G.

D. Multiple Elements or Entities

This characteristic is the existence of multiple elements or entities at multiple levels of complexity. We explore the nature of the four dimensions of systemic competitiveness. Only in this element are we able to find enormous possibilities for interaction between agents that generate competitiveness. This can be explained with an example: it is possible to observe a company as part of the local economy, which is part of a national economy, which in turn is part of a global economy; each of these levels are interconnected and interdependent of each other. You cannot isolate a component or reduce everything to a single level and this is a primary source of complexity. With all these pieces, they interact in different levels, which illustrates the existence of multiple elements interacting in different scales in a complex system [1] [8].

E. Non-linearity

Non-linearity describes how the input of a system and its output are not proportional or correspondent to one another. The linearity error arises from the fact that when two or more elements are placed together, the result may not necessarily be a simple addition of the properties of each of these elements in isolation; on the contrary, a combined effect can be achieved which is greater or lesser than the simple sum of each part. In other words, we cannot expect that an action taken in a special circumstance may result in the same, if applied to another almost equal phenomenon; even the slightest of change can provoke very different outcomes [9].

F. Connectivity

Connectivity refers to the level of communication and interaction between agents in the system. As the connectivity index increases among the components of the system, it becomes the nature and structure of these connections that define it, the way in which these connections and emerging relationships are now the main issue. At a critical level of connectivity, the system stops being a set of pieces and becomes a network of connections. At this point, the most important consideration is how things can flow through the network because now, the system is the network. If a firm develops a strong relationship between its components, then the firm becomes network oriented to developing economic or not-for-profit activity [1].

G. Autonomy and Adaptation

Within a complex system, the elements have a degree of autonomy, often through their ability to adapt to their local environment according to their own set of instructions [10]. Without centralized coordination and with a degree of autonomy, the capacity of the self-organizing elements emerges. These elements can synchronize their states or cooperate with each other, leading to the emergence of new organizational guidelines from a bottom-up perspective. With the emergence of autonomy and adaptation as attributes, it creates the capacity for a variety of different means of responding to a phenomenon, which implies that a complex system is usually heterogeneous with high levels of diversity and ecosystems, with societies and cultural aspects being considered as a good example of this characteristic [1] [11].

III. Methodology

In this section, we explain our approach to the phenomenon and discuss the methods and strategies used to accomplish the proposed goals and answer the research questions.

A. Research Approach

The approach taken to complete this research was quantitative, since it required the collection of data to test hypotheses raised on the existing variables, based on numerical measurement and statistical analysis. To establish patterns in behavior of firms in the manufacturing industry, questionnaires were employed with the purpose of

identifying whether efficient KM analysis, from a complexity approach in a systemic perspective may increase the ability to generate competitiveness by firms to be analyzed as complex systems. Complexity and KM need to be studied as an approach to further model and determine the strategies that increase performance in companies, especially in knowledge-based firms.

The scope of this research is conceptual and present categorical analysis, since variables are applied together to obtain a successful result. Knowledge management, complexity and competitiveness are investigated to explore their ability to generate competitiveness within the manufacturing industry.

B. KM Toolkits

Following the work of North and Babakhanlou [12], we apply 5 KM toolkits to a set of knowledge-based firms in order to obtain information on how they are able to develop knowledge and how agents interact. The KM tools to apply are: (1) Competency Matrix, (2) Knowledge café, (3) Lessons Learnt, (4) Idea Competitions, and (5) Mapping the Business Intelligence Process.

C. Research Questions

- How does the use of knowledge management influence competitiveness in knowledge-based firms?
- How does the approach of complexity theory increase the understanding of competitiveness in knowledge-based firms?

IV. RESULTS

This research is part of a project that involves several knowledge–based firms in the region of Tijuana (Mexico) and San Diego (USA), where complexity increases due to different cultural, socioeconomic, legal and political structures and characteristics. We identify the importance of the complexity approach by performing an analysis on each firm's interactions. This analysis involves all members of the organizations, including employees, customers, suppliers, and stakeholders.

Previous studies have shown that relationships and interactions between upper and lower-levels of influence, inside an organization, develop different knowledge towards the system [1] [13]. As we can see in Figure 1, there are four levels of competitiveness analysis: Micro, Meso, Macro and Meta; KM flows between macro-level toward micro-level and also from meta-level towards micro-level, also occurs between peers in each level [1]. We acknowledge that macro-level must embrace and facilitate the knowledge generation through public policies.

With these results, we confirm that by following a complexity approach, it is a more adequate and holistic approach to analyzing competitiveness than traditional structural analysis of knowledge behavior. Complex systems are all around us. In most cases in organizations, it is taken for granted that they are complex systems and agents coexist and behave with ignorance of the final result of this organizational structure, but that does not prevent their individual contribution to the system. Complex systems are an approach to model problems, organizations and social groups in the world around us but, it is not necessarily an approach that can predict what is going to happen.

For this reason, organizations can be analyzed from the perspective of complex systems, since their behavior is explained more in terms of interactions than the characteristics of the agents that are part of it. The interactions facilitate the emergence of new conditions that improve the situation of the organization and develop better elements of adaptation and evolution in the environment; this means that the system not only accommodates the changing conditions, but also transforms itself and its environment.

This can be used to understand competitiveness as an emergent property of the system. Not in all environments can a firm become a competitive one, so, the complexity of its behavior is part of the result from interactions, rather than internal capabilities. Following the relationship between agents and variables before and according to complexity theory approach and expert techniques to define variables, this research was divided into the codes and categories described as part of the variables shown in Table 1.

TABLE I. CODES AND CATEGORIES FOR COMPETITIVENESS

Approach	Code	Category
Human Capital	HC-SCAA	Sports, cultural and artistic activities
	HC-C	Courses
	HC-MT	Management of technology
	HC-PAE	Participation in academic events
Research and development	I+D-RD	Research Design
	I+D-RE	Research Execution
	I+D-RM	Resource Management
	I+D-TIC	Information Communication Tech
	I+D-CI	Context Interaction
Management	MG-PE	Planning and execution
	MG-SRM	Selection and resource management
	MG-AT	Acquisition of technology
	MG-RM	Resource management
Culture	CU-TW	Teamwork
	CU-RO	Result oriented
	CU-L	Leadership
	CU-MGEL	Multiculturalism, gender, ethnicity and language
	CU-IN	Culture of interaction
Interaction	IN-IDIF	Inter department and inter firms
	IN-LE	Ludic events
	IN-OS	Organizational structure
	IN-SS	Self to self

In table 1 we also describe how concepts and construct are defined as in five approaches: Human Capital, Research and Development, Management, Culture and Interaction. As well these approaches derived in several Codes that are used to describe how they are understand and explained in this research. This Approaches and Code classification are part of several studies performed to understand business behavior in terms of competitiveness [14] [15].

TABLE II. RELATION BETWEEN VARIABLES AND AGENTS

Agents / Variable	Employees [Meta]	Managers [Micro]	Internal Stakeholders [Meso]	External Stakeholders [Macro]
Human Capital	HC-SCAA HC-C	HC-MT HC-PAE	HC-MT HC-PAE	HC-SCAA HC-PAE
Research and development	I+D-RE	I+D-RD I+D-TIC	I+D-RM I+D-CI	I+D-CI
Management		MG-PE MG-SRM MG-RM	MG-AT	
Culture	CU-TW CU-RO	CU-L	CU-MGEL CU-IN	CU-MGEL CU-IN
Interaction	IN-IDIF IN-LE	IN-OS	IN-OS	IN-SS

By categorizing these variables into some of their characteristics, we were able to explore the interaction complexity between agents involved in the firms. In table 1 we identify the variables analyzed in this context and their dimensions, while in Table 2 we illustrate how these dimensions present each one depending on the interactions between the agents and the variables. So, their behavior becomes complex and present an increased uncertainty for the firm's competitiveness output.

The modelling of a realistic social system may be understood by resorting to one particular type of architecture or research methodology. In this paper, we introduce Cx as an approach to understand how agents interact according to selected variables. These variables do not include all possible inputs to the development of a desired behavior. That is why one limitation of this research is the necessity to increase the number of variables observed. In Table III it is described how KM, Cm and Cx interact between each other. It is observed than Cx is able to analyze several variables and could explain why KM strategies influences Cm or not, this is because uses a more holistic point of view.

TABLE III. KM, CX AND CM

Var / Var	KM	Cm	Cx	Notes
KM		KM is part of the strategies to increase Cm	KM is a complex strategy, it depends on multiple entities, is a nonlinear strategy and requires a lot of connectiveness	KM is proven to be a strategy to increase Cm
Cm	Cm uses KM and promotes collaborative work in the four levels		Cm outcome is better understand using Cx approach to study the interactions between agents	Levels of Cm: Meta. Micro, Meso and Macro
Cx	Cx approach integrates autonomy and adaptation to KM strategies as well as the KM indications.	Cx explains how Cm is a nonlinear outcome of firm strategy, it has a holistic approach to understand Cm		Cx is a relative novel approach to study KM an Cm

In this work, we thus lay the foundations for a complex description of socio-economic realities, in a process that weaves different available computational techniques to represent social and individual behavior in a contextualized fashion, accommodating agents with limited rationality and complex interactions. Complex systems, such as business organizations, can be understood from the emergence of unexpected or not common properties, such as competitiveness, innovation and creativity; self-organization and evolution; characteristics related to nonlinear behaviors far from equilibrium and are not tied to a location of the firm.

The research activity of the business organization, as a complex system, can be approached from the study of connectivity among agents, centralization, limited instability and generation of novelties, in addition to many examples. In any case, the understanding of the organization project lines of research around topics such as leadership, motivation, competitiveness and complexity, innovation in complex systems, decision making in decentralized organizations, strategy and complexity, collective action construction in systems self-organized, among others. This approaches do not depend on the location of the firm, it is evident that KM, Cm and Cx are present in any firm that where part of this research.

KM is part of the complexity of organizations. The common process for knowledge evolution is in several ways associated with competitiveness, it includes knowledges production, knowledge distribution and the policies to implement and make knowledge profitable. The way knowledge increases competitiveness inside and organizations depends in the attitude of involved agents and the willingness to share and exploit knowledge in the benefit of the organization.

V. CONCLUSION

Cm, Cx and KM are related in the process of agent interactions inside an organization in firms located in Tijuana, Mexico and San Diego, California. The characteristics of Cx as a relative novel approach to organizational studies: multiple elements, nonlinearity, connectivity and autonomy, apply to Cm success, it is important to understand that KM is a strategy and pursue to increase Cm, but Cx helps to know why in some cases is a success and in other it is not, in this research the strategy taken by the firms varies depending on the country they're in. Cm has several elements: meta level, micro level, meso level and macro level, added to this is the existence of

several agents in each level, so to integrate the influence of every one of these levels, it is recommended to use Cx approach to evaluate how KM is going to make a difference inside the organization.

It is concluded that a complex system is a valid approach to managing knowledge within knowledge-based firms. Strategies and approximation to knowledge must be created to provide stakeholders with access to structured and unstructured information, assisting them with actions to improve coordination, communication and collaboration in day-to-day business operations. The KM system must assist employees in understanding a firm's knowledge, tailoring information to people to enable them to work more efficiently and effectively together [16].

Employees should take advantage in using information technologies to perform KM practices and then to analyze outputs from a complex theory approximation. Nevertheless, there are certain factors that would influence its success, including the assumption that human resources are indispensable for the growth of an organization. However, it is mandatory to implement a strategy to help develop KM as a tool to face the challenges that a turbulent environment generates between these elements.

The bi-national region of Tijuana and San Diego are a particular complex one. In this area coincide several factors that increased the difficult to understand social and economic issues. By example: different languages, cultural customs, religions, family structure, ethnic dynamics, educational and government differences. And this is only a few ones that can be addressed. Add to this, it is possible to understand that motivation and beliefs to develop strategies inside an organizations are different and they are influenced by the notion of self-awareness present on the employees and the owners of this firms.

Previous studies [17, 18] show that KM goes hand-in-hand with different approaches to understanding its role in developing firms and for economic results, due to the correct management of knowledge leading to effective competitive development in firms. KM is capable of generating e advantages between companies and achieves the increasing of their competitiveness; this result is independent on the locations of the firm. It is likely that if a company implements KM strategies, these are going to increase the possibility of a better competitiveness performance regardless to the country where the firm is operating and developing these actions.

We answer the research questions raised at the beginning of this article about the application of KM and complex theory to create competitive advantage, following a theoretical and conceptual approach. Through an enhanced literature review, it will help us base the hypotheses and identify the results of the study, including future studies using statistical analysis such as structural equation modelling and social simulations applying other computational tools to understand the phenomena. By using a KM, Cx and complex theory approach within work processes, it is possible to create competitive advantages and, in fact, increase competitiveness.

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