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Integrated management systems as complex adaptive systems

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Abstract
It is a difficult task to avoid the "smart systems" topic when discussing smart prevention and, similarly, it is a difficult task to address smart systems without focusing their ability to learn. Following the same line of thought, in the current reality, it seems a Herculean task (or an irreparable omission) to approach the topic of certified occupational health and safety management systems (OHSMS) without discussing the integrated management systems (IMSs). The available data suggest that seldom are the OHSMS operating as the single management system (MS) in a company so, any statement concerning OHSMS should mainly be interpreted from an integrated perspective. A major distinction between generic systems can be drawn between those that learn, *i.e.*, those systems that have "memory" and those that have not. These former systems are often depicted as adaptive since they take into account past events to deal with novel, similar and future events modifying their structure to enable success in its environment. Often, these systems, present a nonlinear behavior and a huge uncertainty related to the forecasting of some events. This paper seeks to portray, for the first time as we were able to find out, the IMSs as complex adaptive systems (CASs) by listing their properties and dissecting the features that enable them to evolve and self-organize in order to, holistically, fulfil the requirements from different stakeholders and thus thrive by assuring the successful sustainability of a company. Based on the revision of literature carried out, this is the first time that IMSs are pointed out as CASs which may develop fruitful synergies both for the MSs and for CASs communities. By performing a thorough revision of literature and based on some concepts embedded in the "DNA" of the subsystems implementation standards it is intended, specifically, to identify, determine and discuss the properties of a generic IMS that should be considered to classify it as a CAS.

Keywords: complex adaptive systems, integrated management systems, properties, emergence, agents.

1. INTRODUCTION

Winston Churchill once stated that 'Out of intense complexities, intense simplicities emerge'. Although not a scientific novelty, the complexity construct has been recently increasingly addressed by a great deal of scholars due to, among others, the emergence of mathematical tools that deal with some and other way, seemingly impenetrable fields of research. Revolving around this construct one often finds concepts such as chaos, symmetry, entropy, modularity, hierarchy, nonlinearity, connectivity, synchronization, schemata, homeostasis (equilibrium), self-regulation and self-organization. Inherent to this discussion lays the duality organization *versus* disorganization, or more accurately in the present case, organized MSs *versus* entropic or disordered (chaotic) MSs. A proper descriptive approach concerning this latter concept considers that a system "grows" in organization when the amount of information needed to fully describe it decreases. This notion may be accurately understood if one recalls the concepts of crystallinity (lattices- organized system) and amorphous materials (disorganized system) that were addressed at the Chemistry sessions in the yearly years of academic studies. The self-organization construct considers the notion that organization is achieved through local interactions among the agents of a generic system that, on his own, do not have any awareness of their contribution to patterned emergent behavior developed by the whole system.

The systems approach (and the nine complexity levels suggested by the general systems theory) is a paradigm of the current science and considers a minimalistic perspective of a system consisting in a set of elements and a set of relations (Chen and Stroup, 1993). This concept evolved after the realization by the academic and industrial communities that the decomposition of a system under study into smaller subsystems, or components, provides relevant information but not explain all the original system behavior. This seems to concur with

the notion that a system is more than the sum of its parts and, on this issue, one may quote Mainzer (1997) when he stresses that 'Linear thinking and the belief that the whole is only the sum of its parts are evidently obsolete'. Concerning organizational systems and organizations as living and dynamic systems, Wheatley (1993) pointed out the outdated nature of several approaches stating that 'Each of us lives and works in organizations designed from the 17th century images of the universe….We learned to manage by separating things into parts'. Several synergies could be developed when researching IMSs adopting a CASs approach. On one side, although the scientific context may differ from each identified CASs, they all share the same set of properties and, inherently, the methodologies to be adopted to deal with one of them may be valid to deal with all the others. In fact, the opportunity to extend the scope of the research of IMSs from the "claustrophobic" and classic management and systems engineering topics to a new "fresh" research field should not be wasted. On the other side, CAS academic community will certainly welcome the contribution from a new field with a remarkable diversity of agents often operating in turbulent environments and encompassing social, human and organizational nonlinear interactions. From our viewpoint, the following features characterize IMSs as CASs:

- Multiple agents: An IMS encompasses multiple agents (people, organizational structure, equipment, customers, society, shareholders and regulatory requirements, etc.) interacting each other.
- Learning: An IMS is an adaptive system, that is, past experiences condition present and future behaviour.
- Evolutionary or co-evolutionary perspectives: IMSs evolve from external and internal stimulus, which, if one consider an appropriate implementation should promote the co-evolution of the MSs that comprise the IMS.
- Emergence: The structures of an IMS emerge from patterns that have their source in the standards and experience. In addition, some common features (or patterns) may be detected not being dependent on the geographic location, company dimension, activity sector or organizational culture. This emergence results in a structured higher hierarchical order of organization. New properties not identifiable in the subsystems that comprise the IMS emerge after MSs integration.
- Modularity and redundancy which leads to resilience.
- Complexity (encompasses several parts) and nonlinear behaviour: the interrelationships developed among its elements originate nonlinear emergent behavior in which the complexity is higher than the sum of behaviors of its parts.
- Multi-dimensionality in the sense that many different elements interact on many different scales.
- Non deterministic behavior, that is, several responses (outputs) from the system are possible given any cause.

"Complex adaptive systems" is a research topic that encompasses the most different systems typologies either in dimension, degree of complexity, agents involved, physical or organic nature. One may state that there is not a peculiar research environment where this topic is studied and the contributions provided by the research into a distinct system typology may be valuable to other systems presenting different characteristics but encompassing the features that enable them to evolve as CASs. According to the literature, the term CAS has different meanings to different researchers and a consensual definition seems to be a difficult task among academic experts but it is possible to list the agreed properties that a CASs should present.

The revised literature pointed out the adoption of CASs related methodologies to study ecological and biological systems, social systems, organizational systems and MSs, supply chain networks and information systems, among others. Table 1 and Figure 3 list some of the scientific domains and the correspondent bibliographic references where CASs have been identified and studied.

Table 1: Topics crossover concerning CASs.

Topic	References
Social systems	Antonacopoulou and Chiva, (2005b) Eidelson, (1997)
Ecological systems	Anand *et al.* (2010) Hartvigsen *et al.*, (1998) Hulsman *et al.*, (2011) Rammel *et al.*, (2007)
Biological systems	Hegazi *et al.*, (2009)
Airline industry	Igbo, (2013)
Archaeology	Kohler (2012)
Healthcare	Cordon, (2013) Edgren and Barnard, (2012) Martin, (2011) Martínez-García and Hernández-Lemus, (2013) McDaniel Jr. *et al.*, (2009)
Organizational systems, management, innovation and planning	Akgün *et al.*, (2014) Amagoh, (2008) Arévalo, (2013) Bolton and Stolcis, (2008) Bovaird, (2008) Champlin *et al.*, (2013) Diment *et al.*, (2009) Fabac, (2010) Monostori and Csáji, (2008) Nan *et al.*, (2014) Øgland, (2008) Palmberg, (2009a,b) Prewitt *et al.*, (2012) Rogers *et al.*, (2005) Rowe and Hogarth, (2005) Schneider and Somers, (2006) Sutherland and van den Heuvel, (2002)
Supply chain	Choi *et al.*, (2001) Isik (2011) Kanta and Zechman, (2014) Marchi *et al.*, (2014) Pathak *et al.*, (2007) Wycisk *et al.*, (2008)
Information systems and technology	Kovács and Ueno, (2004) McCarthy, (2003) Montmain *et al.*, (2015) Niazi, (2014) Phister Jr, (2010)
Leadership	Lichtenstein *et al.*, (2006)
Language	Beckner *et al.*, (2009)
Product design development and management	Chiva-Gomez, (2004) McCarthy *et al.*, (2006)
Psychology	Barton, (1994)
Economics	Foster and Pyka, (2014) Harper, (2014)
Law	Kim and Mackey, (2014)

Other papers dealt with the abstractive features of the CASs concept (Cornish *et al.*, 2009; Holden, 2005; Kochugovindan and Vriend, 1998; Lansing, 2003), namely, listing the key elements (Ellis and Herbert, 2011), on how to control and efficiently manage them (Abbott, 2007; Laszlo and Krippner, 1998), on the development of methodologies to assess them and their complexity (Avram and Rizescu, 2014) and on the identification of their mechanisms (Akgün *et al.*, 2014). In addition, a significant number of papers focused CASs modeling such as

the one authored by Berry *et al.* (2002), the transfer of the theoretical concepts to a real world environment (Goldstone and Sakamoto, 2003; Pohl, 1999), the proposal of representational tools and improved visualization (Hmelo-Silver *et al.*, 2015; Viste and Skartveit, 2004), the underlying mathematical theory to the concepts (Levin, 2002), how to engineer them (White, 2010) and providing some theory concerning the mechanisms of failure (Woods and Branlat, 2011).

This paper follows with a brief description of the research methodology adopted. The next section, "Results and Discussion", lists the properties or characteristics that were mentioned and adopted by the authors in the consulted bibliography to classify the most various focused systems as CASs. These same properties and characteristics are then targeted and dissected from the view point of the IMSs which, we expect, make our point concerning the classification of the IMSs as CASs. The "Concluding Remarks" section sum up the main topics addressed in the paper and points to potential further work considering scientific synergies between the two concepts (IMSs and CASs).

2. MATERIALS AND METHODS

A thorough revision of literature was carried out in order to proceed with the identification of the main properties that are ascribed in the different published papers and studied systems in order to label them as CASs. Several queries were performed in the soundest data bases, such as the "Web of Science", "Scielo" and "Scopus" and in the repositories of *e*-journals such as "Elsevier Sciendirect", "IEEE Xplore". "Springer" and "Taylor and Francis" containing academic bibliographic resources. The papers considered for analysis were the ones containing keywords such as "CAS", "Complex adaptive systems" and "Complex systems" in the title. Furthermore, although the desirable contribution from several research domains, a theoretical sampling took place of the bibliographical resources considering the topics closely related to IMSs (Organizational systems, management, innovation and planning). In addition, a comprehensive analysis of the sections of the standards that assist in the implementation of the various subsystems commonly combined into an IMS (ISO 9001- Quality MSs, ISO 14001- Environmental MSs and OHSAS 18001- Occupational health and safety MSs) was developed.

3. RESULTS AND DISCUSSION

IMSs are systems of systems and, from a viewpoint of the CASs, are complex adaptive systems of systems (CASoS) a concept proposed and adopted by several authors and entities such as Brown *et al.* (2013) and Sandia (2015) that depict systems where the primordial components are themselves systems, CASs or not, with several agents interacting internally and some features interacting beyond the original boundaries with other features from other subsystem(s). Evolving from a single CAS to a CASoS demands a compulsory redefinition of the boundaries, the assessment of the newly interactions arisen, the identification of novel emergent features and of all the dynamics involved. IMSs encompass several agents such as people, entities and organizations among other (Domingues *et al.*, 2012; Sampaio *et al.*, 2012). Additionally, and as stressed by Almeida *et al.* (2014), IMSs are standardized and certifiable organizational systems implemented by companies that intend at the same time to fulfil several stakeholders' requirements, usually, the customers' requirements (according to the ISO 9001 standard), the environmental requirements (according to the ISO 14001 standard) and the employees safety requirements (according to the OHSAS 18001 standard). In addition to the implementation of these standards it is possible to find out IMSs that comprise other MSs seeking to fulfil several sector specific requirements such as the ISO/TS 16949, the ISO 50001, the ISO/IEC 27001, ISO 13485 and the ISO 22000 (Domingues *et al.*, 2011).

The properties identified and discussed in this section were pointed out in a sample of 58 papers collected as described in the "Methodology and Methods" section. Figures 1 to 3 present the sample characterization concerning the year of publication, the typology of bibliographical resource and the topic or context where the study took place.

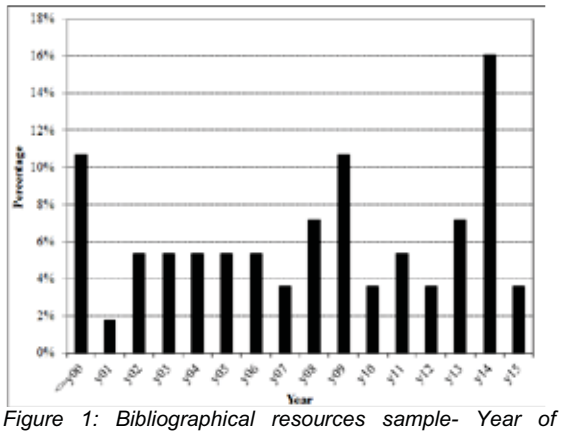

Figure 1: Bibliographical resources sample- Year of publication.

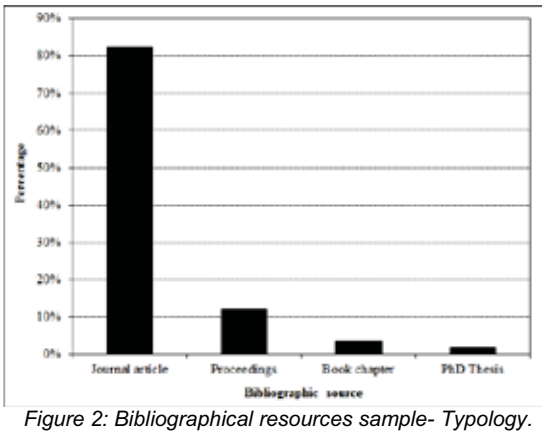

Figure 2: Bibliographical resources sample- Typology.

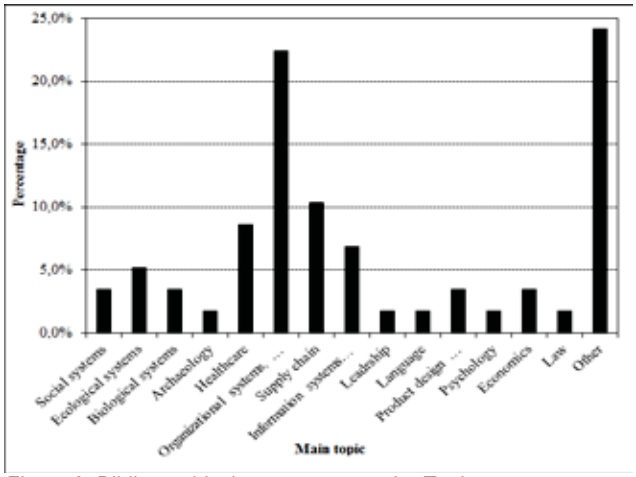

Figure 3: Bibliographical resources sample- Topic.

As one may observe, mainly journal articles (Figure 2) and publications from the last 5 years (Figure 1) were considered. Regarding the main topic addressed by the bibliographical resource (Figure 3) one should point out that the topic encompassing the organizational systems, management, innovation and planning concepts accounts for approximately a quarter of the sampled resources. From our viewpoint, the relevant and diverse contribution of the sampled articles (regarding the year of publication, typology and main subject) assures and improves both the reliability and internal validity of the findings.

3.1. IMSs as learning systems- How MSs learn?

A common feature from all the reported subsystems usually combined into an IMS is the continuous improvement methodology. This methodology, if properly implemented, triggers the stimulus for the learning process requiring that the system “learns” from mistakes and make progress through the identification of the improvement opportunities. Figures 1 and 2 display the continuous improvement construct ascribed to Deming and the Plan-Do-Check-Act (PDCA) cycle attributed to Shewart, both considered two Quality gurus. In fact, not pursuing a detected non-conformity or an improvement opportunity is itself a mistake that will be pointed out in the following internal or external audit. This is commonly and widely reported in CASs related bibliography as the feedback loops. This concept will be addressed later on in this paper.

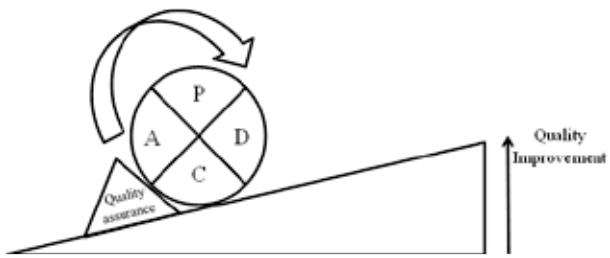

Figure 1: Continuous improvement (Deming Wheel).

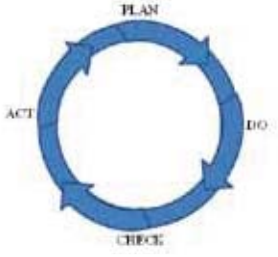

Figure 2: P-D-C-A Cycle (Shewart).

Although from a background that relates mainly to the quality MSs the continuous improvement methodology was later adopted by the other MSs as a proper and suitable tool to assure the learning process.

3.2. Agents that comprise the IMSs and their non-linear behavior- Which agents should be considered and which are the relationships between them?

In opposition to companies operating solely with a MS, a company operating simultaneously with multiple MSs (Figure 3) encompasses different and not always convergent goals seeking to attend several stakeholders' requirements. An IMS encompasses several agents and the relationships between them are not, at this moment, fully understood.

Figure 3: Domain of integrated management.

Among these agents, the individuals supersede the others. Beside the individuals, one may consider as agents, among others, the national bodies that manage environmental and OHS policies, the customers (other companies), the subcontractors, consultants and the company itself (its organizational culture that impacts on the employees, its strategic orientation, etc.). Several studies pointed out the lack of evidences concerning the relationships between the implementation methodologies adopted and the integration level attained (Bernardo *et al.*, 2011), the difficulties of integration and the integration level of MS human resources and the constructs of innovation and satisfaction (Simon *et al.*, 2014b) and event if MSs integration by SMEs was advantageous (Olaru *et al.*, 2014). In addition other papers stressed the lack of understanding of IMSs complexity, its integration levels and possibilities varies among companies (Mežinska *et al.*, 2013). These results illustrate the typology of relationships that one may find when researching into IMSs although it is not fully clear if the relationships are effectively absent or if the instrument that is being adopted to measure the phenomenon is adequate and, if adequate, is reliable.

3.3. Adaptive and (co)evolutionary perspective of the IMSs- How IMSs adapt to internal and external challenges?

One should take into account that the most popular MSs implemented by the companies are, in fact, standardized MSs so they are exposed to the successive external revisions developed in the standards. A closer look at the standards revision process, namely on the inputs collected for the process, disclose other concepts widely reported in CASs- the feedback loops and the notion of different scales of a peculiar phenomenon. The revision process from the most popular MSs, namely that of the ISO standards, is developed from the inputs provided by ISO members being these, usually, appointed by the national bodies that coordinate the quality system in each country. Hence, the revision process is in fact a feedback loop at a macro scale considering IMSs.

3.4. Emergent patterns and properties from the IMSs- What adds an IMS to an existing single MS?

Some properties, not previously discernible in the subsystems, arise and emerge from the integration of MSs. Each of these properties are characterized by a certain number of features that add increased complexity and demands for an analysis of the system through different levels, usually described as micro-, meso- and macro levels. One of these properties is what one may address for as the holistic property. IMSs are autonomous systems but are dependent on the environment (universe that surrounds the boundaries) concerning two critical factors to

their evolution: resources and information exchanges, similarly, to the features pointed out by Oliveira *et al.* (2011) regarding horizontal inter-organizational networks.

3.5. Modularity and resilience

Several researchers pointed out that IMSs do have a modular nature or, at least, may be seen from a modular perspective. The main benefit to be collected from a system that has a modular nature is that although a module may be impaired regarding its performance that whole system is able to reconfigure in order to maintain its functionality, that is, the system has an improved performance when coping with change. Each MS that comprise the IMS has a structure that is common to the other MSs standards and some features that are specific. Concerning the environmental subsystems one can found the relevant feature of the identification and quantification of environmental impacts and regarding the OHSMSs one may found the systematic risk assessment concerning the menaces to the wellbeing of employees.

3.6. IMSs and self-organization- How IMSs manage to self-organize and which are the evidences of it?

Self-organization inherently arises from MSs integration if one consider, for instance, the audit function and the continuous improvement concept. When dealing with the follow up of a non-conformity or an improvement opportunity, in an integrated context, one should consider the requirements from all the stakeholders that should be attended. This constrains the set of possible solutions which, in an integrated context, decrease the degrees of freedom to a hypothetical upgrade proposed to deal with that distinctive non-conformity or improvement opportunity. Thus, in accordance with the definition previously pointed out in the "Introduction" section concerning the construct "Organization", the amount of information to describe the hypothetical solutions to deal with the non-conformity decreases, hence, the system self-organize. To sum up, it is not farfetched the statement that local interactions between the subsystems promotes the emergence of properties, characteristic of each IMS, that were previously (before the integration process) absent.

3.7. IMSs as complex systems

Comparing with other complex systems IMSs are hardly classifiable as fractal systems, *i.e.*, they are not self-similar at all scales. The different subsystems that comprise an IMS do have a common structure, known in the new 2015 revision of the standards as the high level structure (HLS), and this structure should be evidenced at the throughout all IMS levels but some low level elements that share intrinsically intimacy with the stakeholder to whom the standard addresses differ from standard to standard, hence, from subsystem to subsystem. The HLS acts as a command or control module and, due to this fact, the IMSs do not present the properties that are shared by other type of systems, on a related scientific domain, namely, the (hyper)networks (Johnson, 2010). Several strategies and methodologies have been adopted in the intent of "making sense" of the IMS phenomenon, namely, by "normalizing" them to enable comparison. Concerning this issue one may point out the development of maturity models by Domingues *et al.* (2014) and Idrogo *et al.* (2012) and several other models that sought to accommodate an increasingly number of stakeholders (Genaro and Loureiro, 2015; Rebelo *et al.*, 2014).

3.8. Multi-dimensional nature of the IMSs

IMSs are systems of systems with both horizontal and vertical (top-down and bottom-up dynamics), *i.e.*, taking into account an individual one may state that she (he) is affected and impacted by other individuals (horizontal dynamics) and affected by the group and organization where she (he) is inserted (e.g. organizational culture)- top-down dynamics. Nevertheless, it should be pointed out that both groups and organizations are developed based on individuals, on their beliefs, values, actions and aspirations (Johnson, 2010), *i.e.*, one should consider also bottom-up dynamics to accurately model and characterize the whole state of a company. Figure 4 displays the different levels of organization that one may find when researching into IMSs from a CASs perspective. It was adapted from a study concerning organizational learning but, from our viewpoint, suits accurately to the research field of IMSs and points out the notion that in the IMSs many different elements interact at many different scales. Although several other features that impact on the performance of the IMS (such as the culture adopted in the company and its mission) one of the most relevant, certainly, are the individuals that comprise it. These are in fact the 'butterfly wings' that may promote a "game changing" event.

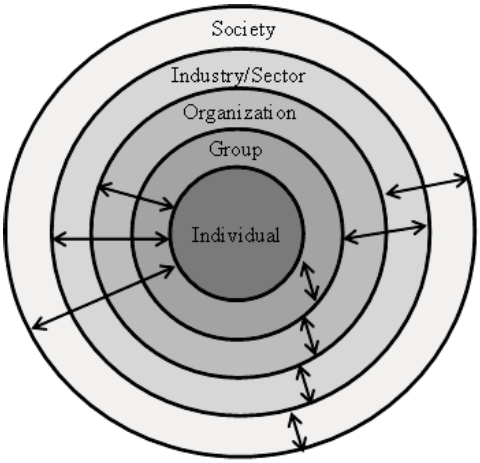

Figure 4: Levels of organizational learning (adapted from Antonacopoulou, 2005a)

3.9. Non-deterministic behaviour of IMSs

At the time, and although some published studies pointing out some critical success factors seems that some of the features that favours integrated management over non-integrated management are not totally accomplished even if, apparently, the implementation conditions are the same. Hence, it is appropriate to state that to distinctive features of the IMSs implementation are ascribed with a remarkable uncertainty. Among those features one may point out the integration level to be attained by the MSs, the expected benefits to be collected, the degree of articulation between the MSs that comprise the IMS, the inertia from the IMS concerning external inputs and its flexibility regarding the adaptation to the revisions from the implementation standards. This latter issue is particular relevant due to the major revisions expected in 2015 of both the ISO 9001 and ISO 14001 standards. Other relevant feature is the development of the audit function that apparently, considering the findings of the study from Simon *et al.* (2014a), differ according to its own nature- internal or external.

4. CONCLUDING REMARKS

This paper intended to point out some of the properties of the IMSs that match the properties of a peculiar type of systems known as CASs. To our knowledge, this is the first time that IMSs are depicted and dissected from the view point of learning, adaptive and dynamic systems which, hopeful, can be a fruitful contribution and may “open doors” concerning the development of further synergic studies involving the two concepts. By one side the scientific and academic community that address IMSs may collect relevant insights and a new and fresh perspective from the CASs community. On the other side, the CASs or CASoSs scientific communities, more focused on the concept itself than on the scientific domain, will certainly benefit from the reports of a particular system that is singular, often turbulent and that encompasses several agents. Specifically, the occupational health and safety researchers will be particularly fortunate if one consider that seldom are the OHSMS that operate as the single MS in a company (Domingues *et al.*, 2014). It is possible to conclude that IMSs are, in fact, CASoSs, *i.e.*, systems of systems with the capability of adaptation in order to prevail and attain success in its environment.

At the moment, there are several shortcomings that should be overcome so that they do not preclude the approach of IMSs from a CASs perspective. The major concerns are ascribed to the MSs integration phenomenon from an academic point of view, namely, the methodological issues to be adopted in the research design. The research approach concerning the integration of MSs should take into account that this is a contemporary and hardly controllable phenomenon, *i.e.*, in opposition to other systems approached through a CASs perspective the IMSs are not transferable to a laboratory environment. Although the collection of the data and the development of grounded theory may be achieved by qualitative research methods some underlying quantitative mathematical concepts seem to be critical to attain successful outcomes. Other methodological related limitation is the fact that when dealing with IMSs research one deal with a domain closely related to that of social sciences. To other scientific domains that embrace mainly quantitative research methods and that deal with “more easily” measurable variables the notion of a construct (widely adopted by qualitative researchers) is somehow alien

and may be looked with suspicion. In our view, the notion of construct and how to translate it to a mathematical language may be crucial to the development of a IMSs research field backed up by CASs related methodologies. This, we believe, will be the challenge for the next years and quoting once again Winston Churchill 'So, I have myself full confidence that if all do their duty, if nothing is neglected and if the best arrangements are made, as they are being made, we should prove ourselves once more able… to outlive the menace …' of ignorance regarding IMSs '…if necessary for years, if necessary alone.'.

To conclude, and it seems an appropriate metaphor due to the addressed topic, like the flapping wings of a seemingly unaware butterfly that output a hurricane on the other side of the world we humbly hope that this paper may impact similarly.

5. ACKNOWLEDGMENTS

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