The Management and Engineering of IT-Intensive Systems: A Systemic Oriented View

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ABSTRACT

Studies in Software Engineering (SwE) and Systems Engineering (SE) disciplines have alerted on the increasing complexity of software-intensive systems in the last 15 years. As a response to this phenomenon, it has been recognized the need to strengthen the SE and SwE curricula mutually through a unified Software Systems Engineering discipline. In turn, a common definition of the Information Systems (IS) discipline indicates that IS concerns with the study of Information Technology-based systems (IT) for managerial purposes as well as with the dual nature – technical and social- of its management. This paper, -product of a research in progress- develops the case for a Management & Engineering of IT-intensive Systems view under the following rationality: (i) the technical and social complexity of the issues related with the emergent information systems -built on software-intensive systems- that is demanded by organizations escapes of the scope of knowledge of the traditional IS discipline, (ii) the IS discipline has arrived to such degree of fragmentation that it has became in a set of knowledge islands, and (iii) an interdisciplinary –systemic- approach provides the adequate philosophical paradigm and methodological research tool to cope with this phenomenon through the systemic interaction of traditional IS, SwE and SE disciplines. In pursuit of this purpose, this paper reviews the origins, foci, objects of study, main disciplines of reference, and main research methods used in these disciplines, and uses a Systems IS research framework for theoretically justifying their integration. Discussion of benefits and barriers for its development are also finally reported.

Keywords: IT-intensive systems, Information Systems, Systems Engineering, Software Engineering, Interdisciplinary Research, Systems Approach.

INTRODUCTION

Studies in Software Engineering (SwE) (Andriole & Freeman, 1993; Sommerville, 1998; Boehm, 2000, 2006) and Systems Engineering (SE) (Sage & Cuppan, 2001; Keating et al, 2003) disciplines have alerted on the increasing complexity of software-intensive systems in the last 15 years. For the former case, this identification has been through the concepts of software-intensive systems (Andriole & Freeman, 1993; Boehm, 2000); socio-technical software-intensive systems (Sommerville, 1998) and software-intensive systems of systems (Boehm, 2006) while that for the latter case, through the emergence of the concepts of system of systems (SoS) (Sage & Cuppan, 2001; Keating et al, 2003) and complex systems (Senhar & Bonen, 1997; Mage & de Weck, 2004; Cleary, 2005).

As a response to this phenomenon, it has been recognized the need to strengthen the SwE (Sommerville, 1998; Hecht, 1999; Bate, 1998; Johnson & Dindo, 1998; Denno & Feeney, 2002) and SE (Brown & William, 2000; Rhodes, 2002) curricula mutually. Furthermore, a unified Software Systems Engineering discipline it has also posed by other studies (Andriole & Freeman, 1993; Thayer, 1997, 2002; Boehm, 2000). In turn, the SE disciplines per se, has been also required to wide its scopes to managerial duties (currently it is taught as Engineering Management, Industrial Engineering or Project Management topics) in order to SE provides the systems-view for managing the complete organization and only the traditional technical processes for engineering a product or provision a service (Farr & Buede, 2003; Arnold & Lawson, 2004; Emes et al, 2001).

Hence, while the SE and SwE disciplines have started to interact in the last 15 years to address the design of complex software-intensive systems -but composed of hardware components also like automotive systems, airspace systems, mobile telephone systems, etc-, a highly related discipline –*e.g.* Information Systems- has largely ignored such issues. Then, given a common definition of the Information Systems (IS) discipline as concerning with the study of computer-based systems –now called Information Technologies - for managerial purposes as well as with the dual nature – technical and social- of its management process (MIS Quarterly, 2006) and where the IS development (Nunamaker et al, 1991) and the IS design process (Hevner et al, 2003; 2004) are considered part of the practitioners duties and research paradigms, this paper -product of a research in progress- develops an initial case for a Management & Engineering View of IT-intensive Systems as discipline.

This perspective is developed under the following rationality: (i) the technical and social complexity of the issues related with the new information systems demanded by organizations escapes of the scope of the traditional monolithic view of IS, (ii) the IS discipline has arrived to such degree of fragmentation that it has became in a set of knowledge islands, and (iii) an interdisciplinary –systemic- approach (Ackoff, 1960) provides the adequate philosophical paradigm and methodological research tool to cope with the phenomena of interest to be studied through an unified view of IS, SwE and SE disciplines.

In pursuit of this purpose, the paper is structured as follows: in next section an extended review (Mora et al, 2006a) of the origins, foci, objects of study, main disciplines of reference, and main research methods used in these disciplines is reported. We continue -by using a systemic IS research framework (Mora et al, 2006b, 2007)- with the theoretical justification of the integration posed through an initial case. Finally, we conclude with a brief discussion of the benefits and barriers for its further development.

A SYSTEMIC REVIEW OF THE SE, SWE AND IS DISCIPLINES.

The concept of modern SE, SwE and IS disciplines –*e.g* as systematic generation and deployment of scientific knowledge- emerged historically during late 1930's for SE and late 1950s and 1960 for IS and SwE respectively. Some reports (Buede, 2000; Gonzalez, 2005; INCOSE, 2004) point out that SE principles have been used by urban architects or early civil engineers through the construction of large-scale systems such as: Egyptian pyramids, Roman aqueducts, bridges and buildings, and early mechanic and naval engineers with heavy industrial machinery, trains and ships. However, modern and systematic SE discipline is born with the integration of a multidisciplinary engineering team in the British air defense systems in 1937, the first SE course at MIT in 1950, the establishment of a systems development division by RAND corporation in 1955, and the publishing of the first textbook on SE from H. Goode & R. Machol in 1957. At present, after 40 years, the existence of undergraduate and graduate programs discipline (Brown & Scherer, 2000), professional societies as INCOSE, worldwide conferences and scientific journals proves that SE is a well-recognized discipline.

The term of IS –originally named Management Information Systems- was coined in 1958 by Leavitt & Whisler (cited by Adam & Fitzgerald, 2000). The first textbook appears in late 1960s (Dearden & McFarlan, 1966; cited also by Adam & Fitzgerald, 2000) as well as the first graduate program in the University of Minnesota. As the same as the SE discipline, 40 years after, the IS discipline is well-recognized by the existence of the similar aforementioned indicators (*e.g.* programs, conferences, journals, etc). In turn, SwE concept was formulated in a NATO's Conference in late 1960s (Bauer, 1969; cited by Pressman, 1997) despite of the development of computer programs, languages and operating systems was done previously from the 1950s. However, these technological developments are related with Computer Sciences or Electrical Engineering disciplines. The first SwE textbook appears on the early 1970s, but is until the 1980s and the 2000s when the first graduate and specialized undergraduate programs in SwE are available respectively. However, despite of the delays in its evolution, the current existence of focused graduate and undergraduate programs, professional societies, conferences and journals in SwE supports evidences to consider the SwE as a discipline separate from its origins –*e.g.* Computer Sciences or Electrical Engineering-. Hence, the historical order of apparition of these disciplines suggests that SE is a more mature discipline –supported by the large-scale projects where it has successfully used as well as by the stability and standardization of its theories, methods and tools developed (Honour, 2004) -. In second place is the IS discipline and finally the SwE discipline. However, recent studies in the three disciplines –fostered by the increasing of IT-based systems and inherently complexity- are alerting on a required convergence or interdisciplinary curricula, research and praxis. In next section we develop an initial case for it, but it is required firstly to analyze the current foci, disciplines of reference and body of knowledge as well as the main research methods for each discipline.

According to Mora et al (2006a) there is not a standardized definition of what is SE, SwE and IS. Nevertheless, from several sources (INCOSE, 2004; SEI, 2003; MIS Quarterly, 2006), it is feasible to report the common definitions. Their systemic analysis is done with the construct <PQR-system> (Checkland, 2000) and exhibited in Table 1. From Table 1, it could seem that the systems of study for each discipline are disparate: a physical system, a software system and an IT-based system. However, the definition for SE implies the integration of several engineering disciplines as the physical system demands a special expertise for its development. In particular it has been identified a trend on the increasing development of systems coordinated by SE that are intensive in software (Andriole and Freeman, 1993; Bohem, 2000, 2006). Rhodes (2002) –nevertheless – remarks that software is other critical component like hardware and people involved in the entire man-made organizational system developed by systems engineers.

In turn, in the SwE discipline has been suggested that software systems must be considered as socio-technical software-intensive systems –e.g. "*systems where some of the components are software-controlled computers and which are used by people to support some kind of business or operational process … therefore, always include computer hardware, software .., policies and procedures and people … [and] operate in a systems-rich environment where different systems are used to support a range of different processes*" (Sommerville, 1998, pp. 115).

For the IS discipline, the new definition of software systems corresponds to what is considered an *Information System* (Mora et al, 2003). Furthermore, as it was already indicated, SE discipline is facing the challenge of design and development of more very complex and large systems where not only the technical or operational issues are relevant but also the political and economic ones. A specific new direction on these new demands is through the concept of System of Systems Engineering (SoSE) (Keating et al, 2003). Hence, then there are initial evidences of a required interaction between the SE, SwE and IS disciplines due to the common sub-systems or components based on software or IT in the whole systems addressed by SE.

Table 2 exhibits the relation of the three disciplines of interest with their reference disciplines through a qualitative 5-points scale from 1 (very low support) to 5 points (very high support). These disciplines shares common reference disciplines. Table 2 was populated from a conceptual analysis of several sources (Sage, 2000; Emes et al; 2005 for SE, SWBOOK (IEEE, 2001) for SwE, and Culnan & Swason, 1986; Vessey et al, 2003; Glass et al, 2004; for IS). A different grey intensity level is also used in the cells to emphasize the support score assessed for each discipline. From Table 2, some useful inferences can be supported. Firstly, SE and IS disciplines have been shaped by at least two fundamental disciplines (IE/OR and MS&OR for SE; B&OS, S&BS and IS self-referenced for IS). However, for the case of SwE seems to be a weak disciplinary reference support where only CSc (e.g. with a 5 points level) was fundamental in its original development. Furthermore, SwE was largely considered as a research stream and body knowledge of Computer Sciences (Denning et al, 1989). Nevertheless, in the last decade, it has been recognized in SwE the relevance of disciplines such as: SE, MS&OR, and B&OS (Kellner et al, 1991; Fuggetta, 2000). Secondly, despite of the Systems Science should be a common discipline (at least by the utilization of the concept *system* in the name of two disciplines and the emergent software-intensive system engineering discipline posed for SwE), only SE has kept it as strong theoretical foundations for the discipline.

In the case of IS, Systems Science was an original discipline of reference as main two IS research frameworks report (Nolan & Wetherbe, 1980; Ives et al, 1980). However, despite some proposals have been reported in IS literature to re-incorporate it (Mora et al, 2003; Gelman et al, 2005; Alter, 2006), few evidences of a reincorporation of Systems Science exist at present. SwE also seems to be an

Table 1. A systemic comparison of the conceptual definition of the SE, SwE and IS disciplines

PQR-system Construct	**Discipline**		
	<S: Systems Engineering>	***<S: Software Engineering>***	***<S: Information Systems>***
<S> is a system to do <P> …	… is an interdisciplinary approach and means to <**P**: enable the realization of successful systems>	… is the technological and managerial discipline concerned with <**P**: systematic production and maintenance of software products>	… [is the discipline] <**P**: concerning [to IT-based systems] >
through <Q> …	… < **Q**: [the integration of] all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation [and] considers both the business and the technical needs of all customers >	… that are < **Q**: developed and modified>	… <**Q**: [the scientific study and] the development of IT-based services, the management of IT resources, and the economics and use of IT >
in order to contribute to achieving <R>	… with the <**R**: goal of providing a quality product that meets the user needs>	… on <**R**: time and within cost estimates>.	… <**R**: [positive] managerial and organizational implications>

Table 2. Reference disciplines for SE, SwE and IS disciplines

Disciplines of Reference	**SE**	**SwE**	**IS**
Industrial & Manufacturing Engineering	●●●●●	●	●
Management Sciences & Operations Research (MS&OR)	●●●●●	●●●	●●●
Business/Organizational Sciences (B&OS) (Economy, Accounting, Marketing, Finance)	●●●	●●●	●●●●●
Social/Behavioral Sciences (S&BS) (Psychology, Sociology, Political Sciences, Law)	●●●	●	●●●●●
Mathematics and Statistics	●●●	●	●●●
Other Engineering and Physical Sciences	●●●	●	●
Systems Sciences (Systems Thinking, Systems Dynamic, Soft Systems , Critical Systems)	●●●	●	●
Computer Sciences (CSc)	●	●●●	●●●
Software Engineering	●●●	●●●●●	●●●
Systems Engineering	●●●	●●●	●
Information Systems	●	●	●●●●●

isolated discipline with few interactions with Systems Science. New proposals to interact with SE could robust it. Thirdly, while SE and SwE disciplines have started to acknowledge the need to interact between them in order to study and develop better software-intensive systems, the IS discipline still ignores this fact. Few efforts have been reported and more related studies in IS research despite do not address the SE discipline directly, are focused on a Design/Engineering paradigm (Hevner & March, 2003; Hevner et al, 2004). However, from a systemic view it can be argued that the SE discipline is a clear reference also for IS and it has been largely ignored in IS research, teaching and praxis.

Table 3 exhibits the main knowledge areas and general research streams derived for these disciplines from several sources. From Table 3, a first inference is that SE and SwE disciplines –by its engineering heritage- are most likely to interact in next 25 years. The IS discipline, in contrast seems to be unaware of the dramatic changes and challenges that world organizations are demanding via the emergence of complex socio-technical systems. A second argument is that in the cells with very low interaction (value of 1 point) is required an increment in the interaction in order to the discipline reduces the lack of such body of knowledge and with it can have a entire and holistic view of the systems studied and intervened. This implies –according to the Systems Approach- that any system only can be understood if it is studied: (i) from two perspectives (like a unitary whole or a set of parts interdependent) and (iii) within its wider system and comprising internal subsystems (Ackoff, 1971; Gelman & Garcia, 1989). Details of the need of Systems Approach in IS discipline has been also reported (Mora et al, 2003; Alter, 2003; Gelman et al, 2005; Mora et al, 2006b). Finally, Table 3 shows that SE requires fewer missing interactions than other two disciplines. A strong implication of this situation is that systems engineers are more holistically trained to cope with the study and implementation of large-scale and complex systems than software engineers and information systems practitioners. It is also worth

Table 3. Main knowledge areas and research topics for SE, SwE and IS disciplines

Main Knowledge Topics of Study and Teaching in Graduate Programs	**SE**	**SwE**	**IS**
Systems Engineering Foundations	●●●●●	●●●	● (Required)
Systems of Systems Engineering	●●●●●	●●●	● (Required)
Frameworks and Standards/Models of Processes for SE	●●●●●	●●●	● (Required)
Systems Engineering Management	●●●●●	●●●	● (Required)
Human Systems Engineering	●●●●●	●●●	● (Required)
Model and Simulation of Systems	●●●●●	●●●	● (Required)
Systems Thinking and Systems Foundations	●●●	● (Required)	● (Required)
Business Process Engineering	●●●	●●●	●●●
Systems Software Engineering Foundations	●●●	●●●●●	●●●
Frameworks and Standards/Models of Processes for SwE	●●●	●●●●●	●●●
Software Engineering Tools and Methods	●●●	●●●●●	●●●
Software Engineering Management & Quality	●●●	●●●●●	●●●
Information Systems Foundations	● (Required)	● (Required)	●●●●●
Business Foundations	●●●	● (Required)	●●●●●
Information Systems Technology	● (Required)	●●●	●●●●●
Information Systems Management	● (Required)	● (Required)	●●●●●
Frameworks and Standards/Models of Processes for IS	● (Required)	● (Required)	● (Required)
Specific Domains and Careers of Applications	●●●●●	●●●●●	●●●●●

Table 4. Main research approaches for SE, SwE and IS disciplines

Research Paradigms	SE	SwE	IS
Theoretical Approach (Theorem Proving, Mathematical Analysis, Conceptual Analysis)	●●●	●●●●●	●●●
Modeling Approach (Conceptual Modeling, Mathematical Modeling, Simulation)	●●●●●	● (Required)	● (Required)
Engineering Approach (Design of Artifacts)	●●●	●●●	● (Required)
Behavioral Approach (Survey, Case Studies, Social Experiments)	●●●	● (Required)	●●●●●

noting that IS frameworks and standards/models of processes (like CobIT, ITIL and derived) are scarcely researched and taught at present.

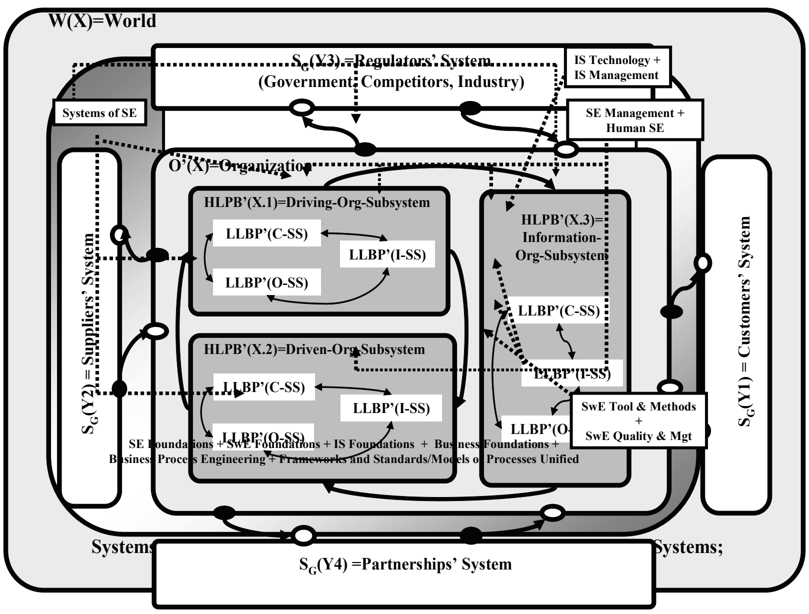
The Table 4 reports the levels estimated of types of research approaches mainly used in the three disciplines. Main categories of research approaches are adapted from Denning et al (1999), Hevner & March (2003) and Glass et al (2004). Theoretical and Modeling approaches can be considered pieces of conceptual research that study concepts, constructs, frameworks, methodologies, algorithms and systems without take data directly from real artifacts. Engineering and Behavioral approaches, in contrast, are pieces of empirical research that take data directly of artifacts, people or organizations.

The Table 4 shows that SE research is conducted mainly through a Modeling Approach–which is a core approach used in Systems Approach- but it also uses the other research approaches in a more balanced way than the other two disciplines. According to Glass et al (2004) theoretical/conceptual studies are more frequent than engineering studies in SwE. However, as a contrast with SE discipline, the modeling/simulation studies are few conducted. For the case of IS, due to its strong historical dependence of O&BS, most studies conducted are classified in the empirical approach (behavioral approach). The theoretical/conceptual studies are in second place and it is because of the B&OS influence. Recent studies have argued the necessity to use modeling/simulation (Mora et al, 2006b) and engineering approaches (Nunamaker et al, 1991; Hevner & March, 2003; Hevner et al, 2004) in IS discipline. In similar way, other studies have suggested that SwE must conduct empirical research (Kitchenham et al, 2002) and wide the few modeling/simulation approaches used.

THE MANAGEMENT & ENGINEERING OF IT-INTENSIVE SYSTEMS: AN INITIAL CASE

To complete this initial case, a description of how the integrated body of knowledge is required to cope with the management and engineering of complex IT-based information systems is reported by using a systemic IS research framework (Mora et al, 2006b; Mora et al, 2007a, 2007b). Figure 1, shows a mapping of knowledge streams reported in Table 3 into the main systems of interest for each discipline: the information organizational system for IS, the operational (information) subsystem for SwE and the driving, driven, information organizational systems or entire organization within the wider system called *world* and composed of the suppliers' system, customers' system, regulators' system and partnerships' system.

Figure 1. Mapping of SE, SwE and IS body of knowledge into the common systems of interest



Systems Thinking, Systems Foundations and Modeling/Simulation of Systems topics are suggested for being the most essential theoretical foundation for the common new integrated discipline. A systems thinking enables to practitioners and researchers to analyze any complex situation as a particular system of interest. In turn, the different conceptual systemic tools let them elaborate hierarchical models with the level of detail required for being studied or intervened. This holistic view of the situation can accommodate hard, soft and critical perspectives (Mora et al, 2007a), as well as quantitative or qualitative modeling. Fragmented and partial views of the systems of interest are reduced. Systems Thinking correctly applied also enables to formulate problems considering all stakeholders' rights.

In next level of common foundations, we suggest the integration of SE, SwE, IS and Business foundations as well as the topics of Business Process Engineering and Frameworks and Standards/Models of Processes. As it was identified, the most worldwide influential standard of processes (ISO 9000 series) has been founded in eight principles, two of them related with Systems Approach (Principle 5) and Process Approach (Principle 4). Furthermore, standards and models in SE and SwE have finally converged in unique view such as the CMMI-DEV, and ISO/IEC 15504 attest. A missing theoretical link between the concepts of *system*, *process* and *service* is missing but some initial efforts are being developed (Mora et al, 2007b).

The topic of SoSE (Systems of Systems Engineering) is also recommended as part of the body of knowledge of this integrated discipline because the emergence of large-scale and complex IT-intensive organizational and man-made systems. SoSE is an extension to classic SE methods to cope with systemic problems (negative emergent proprieties) generated for the composition of systems which subsystems works themselves as whole systems (Sage & Cuppan, 2001; Keating et al, 2003). In next level, the topic of SE Management and Human SE is suggested to address the organization as a system with your main three subsystems: the driving-organizational, the driven-organizational and the information-organizational subsystems. This view supports a modern cybernetic perspective based in control as a coordination act rather than a coercion act (Gelman & Garcia, 1989; Mora et al, 2003; Reyes, 2007). The IS Technology and IS Management topics are suggested to study and intervene on the information-organizational subsystem that is responsible to generate all IS/IT services in the organization (Mora et al, 2003; 2006a). Finally, to complete the mapping of the topics found in Table 3, the SwE Tools&Methods and SwE Quality & Management topics are required to study and intervene in the three sub-systems within the information-organizational subsystem. Each one of these subsystems, in turn, are composed of *systems* of tasks, personnel, tools&infrastructure, methods&procedures and socio-political issues (Mora et al, 2003; 2006a).

Hence, from the literature reviewed, the four tables of evidences generated and the mapping of concepts exhibited in Figure 1, we consider that an initial case for the interaction of SE, SwE and IS disciplines has been generated. Further research to refine and extend the knowledge and research topics will be conducted in next semesters by authors. Main benefits of this study are: (i) the novelty of the analysis on the body of knowledge of these disciplines that are required to interact in the short-term and be integrated in the long-term; (ii) the identification of the rationality for this interaction and integration suggested and (iii) the availability of a conceptual map of the systems of interest in the three disciplines for easing this interaction/integration. In turn, the main barriers for its acceptance are (i) the willingness for an interdisciplinary and systemic effort required and (iii) the lack of utilization, teaching and research based in Systems Approach in SwE and IS disciplines at present. In the meanwhile, however, we believe that IS and SwE community has been alerted of the emergence of these topics. A similar unified research effort is also conducted by the Service Science Management and Engineering initiative (Chesbrough & Spohrer, 2006). Its link with this research is required for further research.

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