Global Quality Management System in Systems of Systems

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1. Background

Quality Management in *Systems of Systems* (SoS) organizations are characterized by very complex products and organizational structures. Since SoS integrate multiple systems and technologies, the corresponding organizational systems are characterized by great complexity that includes sub-organizational substructures. These organizations usually include various units located at multiple sites, and usually have a global geographical layout, meaning that they are global organizational systems. Such organizations require an efficient and effective organizational system that benefits from operating the structural and global system in a multifaceted, demanding and ever-changing environment, including ever-changing technology and multiple and diverse environments. Their QMS must support both current ever-changing complexity and future adaptations, meet customer demands and regulatory requirements, while also giving the organization added value by being a superlative, tailor-made quality management system(QMS) that is exceptionally relevant, effective and efficient. Gorod et al. [1] review the current literature on SoS, and found that is still in an embryonic state in terms of identifying an effective methodology for achieving the objectives of SoS, and generally defining SoS organizational systems. Furthermore, SoS has grown in importance and correspondingly, there is increasing interest in its concepts and strategies. In this context, there is the motivation to define the relevant QMS for these organizations, which is also a global one.

A QMS is based on compliance with requirements of international standards, that set a global standard. The main and most commonplace one is ISO 9001, which embodies the best practices of quality management and quality certification, and suits a wide range of organizations, and all the other similar standards are based on it. The international standards refer to the QMS of *organizations*. They, refer to all the sizes and types of organizations, from local and single-site organizations to multi-site and global operations (large conglomerates), from those that produce a relatively simple product to those whose products are complex/composite systems or SoS. However, in actual practice, they lack the needed references which are relevant and necessary in highly complex organizations, and organizations with a global geographical distribution—*global SoS organizations*.

A QMS is based on the main principle of these international standards, the Process Approach. When dealing with it, the Business Process Orientation (BPO) approach and Process Maturity are also incorporated. Accordingly, the corresponding Process Approach that underlies the QMS must be scalable for dealing with complex organizations and those having a global organizational system, particularly complex/composite systems and SoS organizations.

QMS is based on compliance with an entire set of requirements, e.g., ISO 9001 [2] and similar. Assurance or evidence of compliance with these requirements make them eligible for Certification according to the standard, and to maintain certification over time. That is, as long as the standard's certification is maintained, the evidence of compliance with all QMS requirements is maintained. Nonetheless, standard certification is based on a 0/1 model, either there is compliance (certification) or there is not. This dichotomous model for the wide range of requirements required from a QMS in fact misses (or lacks) reference to other Process Approaches that express the dynamics of processes. As a result, the entire set of requirements (which is broad and comprehensive, but also subject to applied interpretation) is perceived in terms of the first level, and first level only. This set of requirements does not provide a sufficient organizational solution for SoS

organizations, especially international SoS. In this context, wider, more comprehensive requirements have already been formulated in the form of guidelines that do not require certification (for example, ISO 9004 [3]). However, even ISO 9004, similar to ISO 9001, does not address the aspects essential to dealing with global SoS organizations.

SoS organizations, as well as other global organizations characterized by high complexity, and very complex QMS, actually miss (or lack) a reference to *systemic approaches*. In this regard, the comprehensive requirements—guidelines of ISO 9004—can be extended in terms of System Maturity to these kinds of organizations. This systems approach is considered alongside other Systems approaches such as Systems Thinking—an interdisciplinary conceptual framework that is reviewed and described in the Literature Review.

Global Quality Management System (G-QMS) is a new term that has not received sufficiently attention in the research arena, nor is it clearly expressed in the quality management standards (although they are international standards). The somewhat flexible and ambiguous definition of the Process concept in the ISO 9001 and ISO 9004 does not address the level of process complexity of global organizations [4], including their systemic complexity. Furthermore, there is still no global quality management strategy, nor is there a set of requirements or guidelines for it. The Process Approach on which the international quality management standards are founded has the capacity to be expanded. In this broadening Systems approaches shall be considered. Extending the Process Approach underlying the QMS standards is necessary and consistent line with the perspectives and principles of systems theories as well as those of the Systems Thinking. When dealing with organizational systems and QMSs in SoS organizations, systematic approaches should be incorporated. The perspectives and principles (and possibly even the tools) of the System Approaches might be integrated in the structures and characteristics of SoS. According to the SEBoK [5], SoS is a relatively new area, and therefore only limited attention has been given how Systems Thinking might be extended to the issues particular to SoS.

The research field is essentially contemporary and relevant. QMS is a developing field that is increasingly required by organizations, with both internal and external motivations. The internal motivation responds to customer requirements for increased product quality, together with intolerance to faults and delays. This is especially the case in more complex the organization is (such as SoS), where it is increasingly necessary to deal with product quality and delays in customer delivery. Externally, the motivation responds to regulatory requirements, which constantly evolve and "deepen their grip" on both the product and the organizational processes for its realization.

Each of the disciplines encompassed by this field of research is relatively new and rapidly evolving. International standards for QMS are developed and updated once a decade, and organizations adapt themselves to the updated requirements accordingly. Nevertheless, international standards of QMS are focused on the *organization* as a classic entity and lack the required references to the organizational framework, attributes and characteristics of the SoS. That is, their relevance to the reality in which SoS organizations grow and become established, and with it academic research on SoS, should be evolving. Likewise, international standards of QMS lack the reference to the globalization aspects which are relevant in more and more organizations in today's interconnected, global world, particularly SoS organizations. Moreover, the academic literature on global-QMS is also in an embryonic state. Systems Thinking is also a new, evolving discipline that still lacks a commonly-accepted definition or understanding [6]. However, it offers a perspective and tools that are pertinent and can be supported when integrating QMS in global SoS organizations. Systems Thinking can provide a substantial power and value, which are the basic infrastructure for developing frameworks for elements such as structure, motion, dynamics, interrelationships and interactions, including interrelationships with the environment.

2. What Is QMS and Its Motivation in Organization?

The field of Quality Management in organizations has been developed over the past decades and is framed as a Quality Management System (QMS), a system that strives to improve the overall performance of an organization and provide a sound basis for sustainable development initiatives [2]. A QMS helps coordinate and direct an organization's activities to meet customer and regulatory requirements and improve its effectiveness and efficiency on a continuous basis. International standards for QMS, by which the industry works, provide its definition and scope. They specify a set of requirements that an organization needs to assimilate and implement in order to establish and maintain a QMS in the organization. ISO—the International Organization for Standardization—is a worldwide federation of national standards bodies. The most widely used standard and for a large range of organizations is ISO 9001, which lists all requirements for a QMS.

The QMS is based on the Process Approach, which is explicitly mentioned as the main principle of these standards: "This International Standard is based on process approach to quality management" [2] and likewise in other standards. According to the Process Approach, consistent and predictable results are achieved more effectively and efficiently when

activities are understood and managed as interrelated processes that function as a coherent system. Academic literature also refers to the Process Approach as used in the international standards for QMS as BPO, which is a concept that has been adopted by companies worldwide. Companies that wish to improve their performance and stay competitive are introducing and adopting a process view of business in order to enhance their overall performance [7][8]. The QMS consists of interrelated processes, and understanding how results are produced by this system enables an organization to optimize the system and its performance. The Process Approach/BPO integrates processes into a complete *system* for achieving strategic and operational objectives.

Further to the principles and requirements of ISO 9001, ISO 9004 expands and deepens the QMS, which "provides for organizations to achieve sustained success in a complex, demanding and ever-changing environment, with reference to the quality management principles described in ISO 9001" [3]. Likewise, while ISO 9001 focuses on providing confidence in an organization's products and services, ISO 9004 addresses the systematic improvement of the organization's overall performance [3].

3. QMS in Complex and Global Organizations

The current research deals with QMS in organizations that develop and operate *complex systems products*, and in particular SoS. These organizations have a high level of complexity that emerges from several primary factors that are each complex in their own right: (1) Complex system product is usually multi-disciplinary product involving a relativity high number of different actors from many disciplines, having diverse relationships and numerous integrated systems. (2) An organizational system that is characterized by a multiplicity of processes, and also processes which are complex, including multiplicity of interfaces and interactions. (3) The current reality of complex, demanding and ever-changing environments and technologies. Additionally, the current research focuses on the QMS of the complex organizations which are also global, that have global organizational system and expand into international markets using various strategic options and international operational systems, with global customers and global suppliers. Such organizations have complicated interfaces with both suppliers and customers, and also internally according to their international organizational layout. Furthermore, they operate in a complex, demanding, multi-site environment that changes continually.

The discipline of quality management, although subject to regulatory and standard requirements, is not a dichotomous field where one answer is correct and another wrong. Standardization and regulation are legal realms, and therefore different ways can be found to achieve or comply with the same requirements and guidelines. In fact, the international standards for QMS leave a wide range for applied interpretations of their requirements and guidelines, thereby revealing some flexibility in the QMS structure. Thus, when dealing with complex and global organizations, this space can potentially be utilized to promote a model for QMS structure that will be suitable, relevant and efficient for supporting this kind of organizations.

Businesses in the 21st century operate in an increasingly complex global environment. The global reality and its defining characteristics highlight the need to change how quality management is perceived and implemented, given the increasing complexity and multiplicity of mutual relationships between production, product, services and network processes [9]. The global economy and its characteristics have had a profound impact on the development of the concept of quality worldwide. Likewise, issues related to quality management receive added weight in light of the need to function at a very high level of complexity, which demands intricate administrative and managerial strategies [10]. Globalization provides organizations with many opportunities; however, it also presents management systems with complex challenges. With respect to the organizational QMS, beyond the classical issues associated with local operations, multinational organizations must also cope with challenges presented by the decentralization of the organizational functions. The global setting creates particular difficulties for quality assurance and control managers at different levels, and therefore there is an incentive to define it in regard to the organizational QMS and lay the foundation of a global-QMS, that will be relevant and effective for complex system product organizations which are also global.

4. Global Quality Management System (G-QMS)

As can be concluded, there is great potential in the subject of G-QMS and research that focuses on complex system, global organizations and, especially SoS organizations. Although QMS challenges can be naturally expanded to G-QMS, dealing with G-QMS in global organizations with complex, large-scale systems, requires relating to additional aspects specific to organization of this kind and their characteristics.

A review of the literature on the topic of G-QMS indicates that there is a need for a solid G-QMS philosophy, with emphasis on intra-organizational coordination and process management, but this is remained undefined. According to Kim and Chang [11], Total Quality Management (TQM), which was the conventional term for QMS at the time, addresses a single organizational level, and questions remain open as the discussion expands to the global level. They extend the TQM concept to what they consider to be the next evolutionary stage, Global Quality Management (GQM). In comparing TQM to GQM, the strategic concepts behind TQM are maintained, but GQM enlarges the scope to encompass the concerns of multiple functions across multiple countries, and therefore the subsequent increased complexity of GQM. This requires moving beyond TQM to develop a quality concept that reflects the nature of global corporations and their markets. They called this a basic concept "first seeds" for GQM and noted that further development of the term GQM is needed. Despite the growing use of the term, there is still no agreed definition for GQM, nor is there a universal agreement upon the concept itself [12]. QMS in turn requires systematic leadership innovation. The bigger an organization, the more difficult it is to ensure the unity of goals manage its knowledge and govern changes. Formation of a QMS for a complex economic entity not only shapes the environment for the effective, innovative development of a parent company and its separate business units, but also represents an independent organizational innovation that is able to boost the diffusion of organizational changes and launch the expansion of innovations [13].

The findings reported by Bashan and Notea [4] suggest multiple conflicts and a lack of clarity regarding the integrative management of the various Quality Systems within a corporate group, highlighting the need to plan relevant integration mechanisms for Quality functions. Such integration mechanisms are meant to ensure that the different Quality Systems within a multinational company will be mutually connected and function as part of a single organizational entity, in order to reduce failures and ensure Quality across global processes. According to Barabasi and Frangos [14], who use the term "network organizations" to describe the organizational structure of complex and global organizations, network organizations are formed as part of the expansion process of a company. This creates synergy between organizations, or within a meta-organization, moving from a tree structure to a multi-dimensional network structure. This is one of the most significant changes in the area of complex systems; it results from global competition and raises the question of the level of globalization of the quality system.

5. SoS Organizations

Gorod et al. [1] review the literature on SoS and show that although SoS is a relativity new term, there has been significant development in research and experimental applications in the field, mostly during the last two decades. However, the relevant literature shows that research on SoS is still embryonic, both in terms of identifying an effective methodology to achieve the objectives of SoS and concerning the relevant organizational systems. SoS evolved from the earlier System discipline, which has been studied and developed throughout the latter half of the 20th century. However, a process of rapid global acceleration, especially in the military sector, continued and this made expanding developments in engineering to the next level essential. The objective was to address "shortcomings in the ability to deal with difficulties generated by increasingly complex and interrelated system of systems" [15]. The need for a discipline focused on engineering multiple, integrated, complex systems, led to the emergence and evolution of SoS as a discipline, as evident in the literature since the early 90s. Interest continues to accelerate even today.

Much of the literature deals with the need to define SoS and provides a variety of initial definitions [1][15][16][17], but there is still no agreed definition of SoS [18]. SoS moves the focus from single systems to multiple, integrated complex systems. However, the basic principles of complex systems can be applied to SoS, making it is imperative to use complex systems as a foundation for the research in the field of SoS [1]. The transition to the accepted modern term SoS is introduced in the works of [19][20][21][22]. A recent definition can be found in ISO/IEC/IEEE 21839:2019 [23], which also provides a definition for Constituent Systems. SEBok [5] also uses the term Constituent Systems when describing SoS. Azarnoush et al. [24] emphasize that there is an increasing interest in exploiting synergy between these independent systems to achieve the desired overall system performance. In 2007, the Department of Defense (DoD) published their System of Systems Engineering Guide: Considerations for Systems Engineering in a System of Systems Environment [25], which describes the characteristics of SoS environments and identifies complexities of the SoS.

While the literature in SoS is expanding rapidly, there is no established body of knowledge, and nor management framework that guides our understanding of these complex systems [1]. Gorod et al. [1] presented a SoS management framework which brings together a leading approach to describing SoS (i.e., characterization) and one of their fundamental traits (i.e., networks). Likewise, work is needed to identify and articulate the cross-cutting principles that apply to SoS in general, and to develop working examples of the application of these principles [5]. While System of Systems Engineering (SoSE) is not a new discipline, this is an opportunity for the Systems Engineering (SE) community

to define the complex systems of the 21st century [26]. While SE is a fairly established field, SoSE represents a challenge for the present systems engineers on a global level [5].

6. Systems Thinking and the Systemic Approach

In order to promote a G-QMS in SoS organizations, it is necessary to draw inspiration from and integrate aspects of Systems Thinking and the systemic approach. Systems Thinking is also an emerging domain with many different views regarding its definition, rather than one that is precise and widely-accepted. Monat and Gannon [6] conclude, based on a literature review, that Systems Thinking is a perspective which uses a language and a set of tools. Specifically, it is the opposite of *linear thinking*, and focuses on the *relationships* among components of a system, as opposed to the components themselves. It is *holistic* (integrative) thinking instead of analytic (dissected) thinking. The following focuses on Systems Thinking in the domain of organizational systems, and the motivation for its inclusion. It is limited to matters of scope and definition without presenting examples and applications, although they are widely included in the literature.

Systems Thinking is founded on General Systems Theory [27] and has been applied to a wide range of fields and disciplines. It has great power for solving complex problems that cannot be solved using conventional, reductionist thinking [28][29][30], and can be used to explain dynamic, non-linear and complex organizations and environments. Checkland [31] draws a distinction between "hard" and "soft" Systems Thinking. He states, "Systems Thinking, makes conscious use of the particular concept of *wholeness* captured in the word 'system' to order our thoughts", and "Systems Thinking implies thinking about the world outside ourselves". Senge [29] provides a generic definition: "Systems thinking is a discipline for seeing *wholes*. It is a *framework* for seeing interrelationships rather than things, for seeing patterns of change rather than 'snapshots'". Senge's book presents the background and theory of Systems Thinking, and is pivotal because it applies Systems Thinking to management in organizations. Afterward Anderson and Johnson [32] applied Systems Thinking to practice by defining it as a set of tools, a framework for looking at issues, and a language. Richmond [33] "sees the wholes" and considers Systems Thinking the art and science of making reliable inferences about behavior by developing an increasingly deep understanding of the underlying structure. Systems Thinking can provide a great deal of power and value when dealing with complex and everchanging organizations. Within organizational systems, it deals with elements including *organized complexity*, *system dynamics*, *self-organization* and *structure based on processes* and *relationships*, interconnections as well as emergence. All of these are relevant in both G-QMS and SoS organizations [34]. Thinking systemically also requires several shifts in perception, which lead in turn to different ways to arrange an organizational system [35][36].

Systems Thinking is founded on a *holistic* perspective, thus it does not try to break systems down into components in order to understand them; rather it focuses on how the components *act together* in networks of interaction. Consequently, the only way to fully understand a system is to understand its components as they relate to the *whole*. That is to say, "the whole is greater than the sum of its parts" or "seeing the big picture". Indeed, tackling a problem in its entirety often provides a much more effective solution. Bashan and Kordova [37] introduce a system view of globalization and quality management and highlight the concept of Systems Thinking in the global world. Since it is an interdisciplinary conceptual framework, Systems Thinking can be used as a tool in complex systems organization such as SoS and global organizations. When systems perspective is integrated into the working environment of global organizations, it can form part of its infrastructure and facilitate use of terminology and tools in an environment which is increasingly characterized by the ever-changing complexity often associated with global organizations.

The high level of complexity that characterizes the competitive global environment generates the need to adopt a systems perspective for analyzing how a multinational company develops, and the effect this development has on global quality functioning performance. Specifically, the *systems analysis approach*, which is based on open and complex systems theories, is suitable. In their discussion about the ability of ISO 9001 and ISO 9004 meet the needs of a global quality system, Bashan and Armon [12] recommend adopting an Open System Approach that refers on cross-organizational processes, and the complex of interfaces and interactions that exist between them and their external environment. The classical Process Approach does not provide a framework for the dynamic and ever-changing processes occurring during global company expansion. Rather, global reality requires a different process structure. It was showed that Globalization is a new phenomenon, and insights into its complexity and management methods, including management systems, particularly QMS, are still immature. The need for systemic analysis that addresses this complexity motivations the adoption of systemic analysis tools such as Systems Thinking and Systems approaches, which can be integrated into quality management processes at the global level and contribute to a better understanding of their complexities and diverse dimensions.

In summary, Systems Thinking provides perspective and can be a powerful tool in complex and global organizational systems. It is relevant to and can be supportive integrating QMS in global SoS organizations, but its use in most organizations remains insufficiently developed. The current revision of the SEBoK devotes a chapter to Systems Thinking. However, as the focus is on Systems Thinking concepts, principles, and patterns, the chapter is quite vague and does not appear to integrate the disparate articles into a cohesive whole [5].

7. Two Additional Aspects When Developing G-QMS in SoS Organizations

(a)System Approach and System Maturity in G-QMS

Schematically, the System Approach is an expansion of Process Approach for organizations of relativity high complexity, typically global and SoS organizations. Similarly, System Maturity is an expansion of Process Maturity, a model for assessing and/or guiding best practice improvements in organizational maturity and process capability, expressed on a lifecycle level. Process Maturity is used as an indication of how close a process is to being complete and how capable of continual improvement through qualitative measures and feedback. When dealing with System Maturity, an integrated methodology is introduced to assess system maturity and performance throughout the lifecycle of a system, from concept development, through design, and ultimately to the operational deployment of the system. Yet the literature shows that there is no single integrated methodology for System Maturity.

ISO 9004, which provides guidelines which expand and deepen the requirements for QMS, promotes the use of System Maturity by introducing, in an appendix, a five-level maturity model. Its detailed extension to the entire set of guidelines allows the reference to Systemic Maturity, while this tool is used as a reference [3]. Moreover, other international standards for QMS such as the Sectorial Standards are in development in accordance with this trend.

(b)Reference to the Sectoral QMS Standards

In the last two decades, there has been a trend of differentiation in the realm of quality management, according to sectors of business activity. Quality management standards that began to differentiate in the 1st decade of the 21st century already include the second revision. These international standards include AS9001—QMS requirements for Aviation, Space and Defense organizations [38], ISO 13485—for Medical Device organizations [39], ISO 22163—for Rail organizations [40] and IATF16949—for Automotive organizations [41]. This trend of the sectoral directives is contemporary and actual, with sectoral international standards expanding and deepening the applicability of QMS. Moreover, these sectors are relevant to complex systems and global organizations. This differentiation trend has evolved to provide the applicability of QMS in organizations that develop and operate complex and large-scale systems in a demanding, ever-changing reality. In addition, these sectors are characterized by a *strong customer orientation*, which is an environment where customers are involved in setting the requirements for the standard.

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