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Corporate Sustainability Performance Measurement:

Lessons from System of Systems Engineering

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***Abstract*— The purpose of this paper is to explore the implications of applying a system of systems engineering perspective to corporate sustainability performance measurement. The paper highlights that measuring corporate sustainability is a complex problem characterized by pluralistic goals, ambiguity, uncertainty, emergence, and context dominance. The paper argues that system of systems engineering is specifically intended to address problems of this nature and can therefore help corporate decision-makers understand the challenges in developing a robust sustainability performance measurement system. Following a brief introduction, the paper is organized to: (1) highlight the distinctions between traditional systems engineering and system of systems engineering, (2) briefly review the characteristics of system of systems engineering problems, and (3) discuss the implications of a system of systems engineering perspective for corporate sustainability performance measurement. The paper closes with a brief conclusion and recommendations for further research.**

***Keywords*— corporate sustainability, performance measurement, systems engineering, system of systems engineering, complexity**

I. INTRODUCTION

The concept of sustainability initially emerged as a global issue. However, it is increasingly being applied at the corporate level. While there are ongoing debates on what sustainability means in the corporate context, one possible definition is ‘‘adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today while protecting, sustaining, and enhancing the human and natural resources that will be needed in the future’’ [1]. Evidence of corporate commitments to sustainability can be seen in the growing number of corporate sustainability policies, plans, programs, and reports.

To help measure progress towards their sustainability goals, objectives, and targets, many corporations have also developed sustainability performance measurement systems (SPMS). A performance measurement system may be defined as: “the set of metrics used to quantify both the efficiency and effectiveness of actions” [2]. Building on that definition, a good performance measurement system should “provide accurate information, support strategic, tactical, and operational objectives, should guard against sub-optimization, and include a limited number of performance measures” [3]. A SPMS is like any other performance measurement system, except that it has an overarching emphasis on issues relevant to sustainability. The literature on corporate SPMS is rapidly expanding [see, for example, 4, 5, 6, 7]. However, despite many excellent contributions, there are still numerous questions related to how the development of a SPMS should be approached.

Traditional systems engineering approaches have provided a useful compass in published studies. For example, Searcy *et al.* [8] discussed how Checkland’s criteria for a formal system could provide useful guidance in developing the structure and content of a SPMS. However, while there are several benefits in employing traditional systems engineering approaches to the development of a corporate SPMS, there are also several limitations. These limitations center on the fact that corporate sustainability is fundamentally an amorphous, complex problem. Traditional systems engineering approaches were developed to address unambiguous, well-bounded problems in relatively stable environments and caution must be exercised in applying them outside of these contexts.

In this light, this paper explores the implications of applying a system of systems engineering (SOSE) perspective to corporate sustainability performance measurement. Since SOSE was designed specifically to address complex problems, the paper argues that it can offer insight beyond that provided by traditional systems engineering approaches on the process of developing a robust corporate SPMS. The paper begins with a brief overview of the distinctions between systems engineering and SOSE. This provides a basis for the discussions in the following sections. The next section reviews the characteristics of problems SOSE is intended to address, with an emphasis on its applicability to corporate sustainability. This provides the basis for a discussion on the implications of a SOSE perspective to corporate SPMS in the fourth section. Finally, the paper concludes with a brief summary and recommendations for further work.

II. DISTINCTIONS BETWEEN SYSTEMS ENGINEERING AND SYSTEM OF SYSTEMS ENGINEERING

The concept of a system is central to both systems engineering and SOSE. Many definitions of a system have been published. While the details in these definitions may

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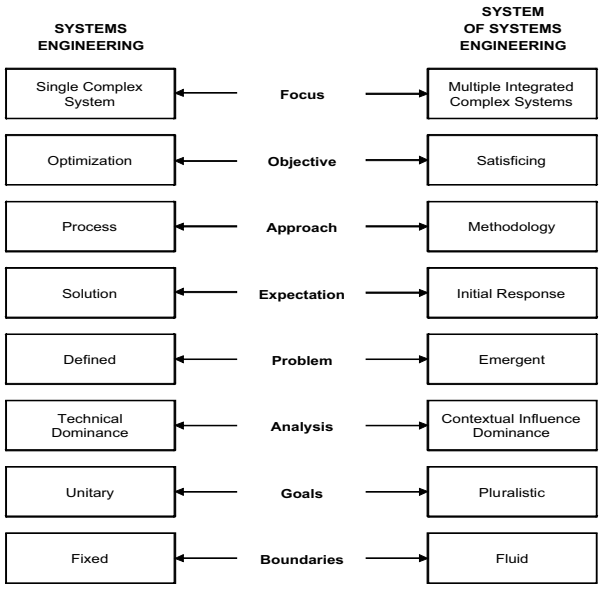

Figure 1. Distinctions between systems engineering and SOSE. (Source: Adapted from Keating et al. [11])

vary, it is well-established that a system is "a set of interrelated components working together to achieve some common objective or purpose" [9]. Both systems engineering and SOSE extend from that principle. Although there is no universal definition of either systems engineering or SOSE, there are examples available in the literature.

The International Council on Systems Engineering (INCOSE) describes systems engineering as "an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem" [10]. Building on that definition, traditional systems engineering approaches tend to emphasize a structured, linear approach to solving well-defined problems with clear goals and boundaries.

Keating *et al*. provisionally defined SOSE as "The design, deployment, operation, and transformation of metasystems that must function as an integrated complex system to produce desirable results. These metasystems are themselves comprised of multiple autonomous embedded complex systems that can be diverse in technology, context, operation, geography, and conceptual frame" [11]. Building on that definition, it is clear that SOSE approaches are intended to specifically address problems associated with integrated complex systems. SOSE is "an extension and evolution of traditional systems engineering" [11].

The relationship between systems engineering and SOSE has been described at length in Keating *et al.* [11]. While there are important similarities, such as a mutual focus on interdisciplinary approaches, there are also many important differences. Figure 1 illustrates several of the important distinctions between the two on the basis of key eight areas.

While traditional systems engineering approaches have proven to be effective in a wide-variety of contexts, Figure 1 highlights that there may be difficulties in applying them to problems with ambiguous requirements. In large, complex corporations facing unstable, unpredictable environments, a SOSE perspective may offer considerable insight into the challenges faced and the options available to at least begin addressing them. However, it is important to caution that "all complex systems problems are not necessarily appropriate for SOSE" [12]. The suitability of SOSE approaches can be better understood by examining the landscape that SOSE is intended to address.

III. CHARACTERISTICS SYSTEM OF SYSTEMS ENGINEERING PROBLEMS

SOSE approaches have to date primarily been applied in military and information technology contexts. However, the applicability of SOSE is not limited to these areas. A review of the characteristics of SOSE problems provides insight into other possible applications. While there is ongoing debate on the nature of these characteristics, Sousa-Poza *et al.* [13] identified seven key conditions SOSE is intended to deal with in the inaugural issue of the *International Journal of System of Systems Engineering*. The seven conditions, and an accompanying definition, are listed in Table 1.

Sousa-Poza *et al.* do not explicitly state that all seven conditions must be present for SOSE approaches to apply. However, as discussed below, all seven provide insight into the challenges associated with corporate sustainability.

TABLE I. CHARACTERISTICS OF SOSE PROBLEMS

Characteristic[a]	**Definition**[a]
Holistic Problem Space	"The nature of the SOSE problem space requires consideration of the technical, human/social, managerial, organizational, policy and political dimensions."
Ambiguity	"The difficulty in clearly demarking problem boundaries, as well as their interpretation, is an inherent characteristic of the SOSE problem domain."
Uncertain	"SOSE problems are not tightly bound, flexing as additional knowledge of the situation is developed."
Highly Contextual	"Context has been previously suggested as the circumstances, conditions, factors and patterns that give meaning and purpose to the SOS (*system of systems)*."
Emergence	"The SOS behavioural and structural patterns, their interpretation, knowledge, understanding and conditions are in constant flux."
Non-Ergodic	"A phenomenological condition of having no defined states or discernable transitions between states."
Non-Monotonic	"Used to refer to a condition in which increases in knowledge are not reciprocated by increases in understanding. Under non-monotonic conditions, decisions are defeasible or tentative."

a. Source: Sousa-Poza et al. [13]

A. Holistic Problem Space

Sustainability is a holistic concept that recognizes the interrelation and interdependence between a vast array of economic, environmental, and social issues. Addressing these issues requires corporations to consider the technical, human, managerial, organizational, policy, and political dimensions explicitly associated with a SOSE problem.

B. Ambiguity

One of the challenges in sustainability is that existing definitions are often interpreted differently by different people. Establishing an interpretation of sustainability in the corporate context is therefore a key challenge. Building on the points in Table 1, establishing analytical boundaries can also be a key challenge. The selection of appropriate temporal and spatial boundaries is particularly problematic.

C. Uncertain

Corporate sustainability is at its root a process of continual transformation. As in SOSE problems, boundaries are not tightly bound and will shift as additional knowledge is developed. Moreover, like all issues characterized by uncertainty, probabilities of success or failure in many corporate sustainability initiatives will remain unknown.

D. Highly Contextual

Corporate sustainability is context dependent. As a result, the effectiveness of any actions to improve progress towards corporate sustainability can only be assessed in light of the context in which they were taken. There is no universally applicable approach to corporate sustainability and different strategies, actions, and solutions will be appropriate in different contexts.

E. Emergence

Corporate sustainability is a dynamic, evolutionary process. It is difficult to capture the requirements of any corporate sustainability initiative at the outset. The sustainability issues a corporation must address, and their relative priorities, are constantly shifting. It is not possible to anticipate all of the challenges that any corporate sustainability initiative will encounter in advance.

F. Non-Ergodic

There is no definitive end point where a corporation can declare that it has achieved sustainability. It is not yet possible to identify exactly what a sustainable corporation looks like and there are no criteria to determine when a solution has been found. A corporation must therefore constantly question whether it is moving towards or away from sustainable practices as a whole.

G. Non-Monotonic

Decisions taken to move a corporation towards sustainability will always be based on incomplete understanding that is continuously changing over time. Since corporate sustainability is such a broad concept, it is simply not possible to know the full consequences of any decision at the time it is made and which courses of action are most appropriate for the given situation.

IV. Implications for Corporate Sustainability Performance Measurement

As illustrated in the previous section, corporate sustainability exhibits the characteristics typically associated with SOSE problems. This has several implications for the development of a corporate SPMS. The key implications are explored below.

- *The initial purpose, goals, and objectives of the SPMS will change over time.* Clearly, a corporation should spend considerable time up front interpreting sustainability in its context, surveying the internal and external environment, and establishing goals and objectives for the SPMS. However, since corporate sustainability is characterized by ambiguity, uncertainty, emergence, and is non-monotonic, these initial formulations must be continually challenged and refined.
- *There is no such thing as an optimal SPMS.* Given the ambiguity, uncertainty, and pluralistic goals associated with corporate sustainability, it is not possible to determine if any particular set of performance measures is the most favorable. This implies that the objective of any SPMS is to provide a satisfactory solution and that no set of performance measures can be considered to be comprehensive.
- *The SPMS will represent an initial response, not a lasting solution.* This builds on the point immediately above. The SPMS must evolve over time in response to changing external conditions, internal priorities, and stakeholder perspectives. It is therefore critical that the SPMS is accompanied by an assessment system to guide its improvement and future evolution.
- *The SPMS does not directly measure corporate sustainability.* Since there is no defined end-state for corporate sustainability, the SPMS cannot directly measure how sustainable any particular corporation is. What it can measure is progress towards clearly defined goals, objectives, and targets. As noted by Bell and Morse, "sustainability becomes defined by the parameters that can be measured rather than the other way around" [14].
- *The quality of the SPMS can only be assessed relative to the context in which it is applied.* Since corporate sustainability is context dependent, the most technically sophisticated SPMS will not necessarily be the best fit for any one corporation. The actual use of the SPMS will be the key determinant in its effectiveness. This implies that a SPMS should contain performance measures that address the unique needs of the corporation and recognize the constraints under which it operates. While

benchmarking of performance is certainly useful, some measures will not be transferable.

- *There will be trade-offs between economic, environmental, and social goals and objectives.* Although sustainability emphasizes the interrelation and interdependence between these three areas, there will ultimately be trade-offs between conflicting goals. This is due to a number of factors, including the pluralistic goals and possibly irreconcilable stakeholder perspectives associated with corporate sustainability. Detailed trade-off criteria to address conflicting objectives that arise in the selection of performance measures should be incorporated into the SPMS.
- *The SPMS should include measures of the whole.* Given the holistic nature of corporate sustainability, corporations should be cautioned against exclusively focusing on individual performance measures. There is a need to evaluate the corporation's sustainability performance as a whole as well. Corporations should therefore consider incorporating composite indices into their SPMS to provide an overall sense of whether it is getting closer to its goals, objectives, and targets as a whole.
- *The process of developing a SPMS must remain flexible*. A rigid process for developing a SPMS is inappropriate given the emergent nature of corporate sustainability. While structured approaches offered by traditional systems engineering should not be entirely discarded, the process must remain flexible and adaptive to accommodate the emerging issues, uncertainty, and the inevitable iterations that are inherent in the process.

Building on the last point, it is important to emphasize that the above discussion does not imply that traditional systems engineering approaches should be completely abandoned in the development of a SPMS. As previous efforts have shown, they can have considerable value in establishing an initial course for the SPMS, scoping the effort, structuring the relationships between sub-systems in the SPMS and the performance measures themselves, identifying the resources required by the SPMS, and establishing feedback processes, among other efforts. However, lessons from SOSE highlight the need to go beyond traditional systems engineering approaches when dealing with a non-linear process, such as the development of a SPMS, in a corporation with multiple integrated complex systems. Although specific approaches to addressing SOSE problems are still in the early stages of development, a SOSE perspective can help corporate decision-makers understand the challenges they face in developing a robust corporate SPMS.

V. CONCLUSIONS

There is an increasing recognition that corporations must address the issue of sustainability. To this end, many corporations have created a SPMS to help measure their progress towards their sustainability goals, objectives, and targets. However, developing a robust corporate SPMS is a complex problem that involves many challenges. This paper highlighted several of these challenges by viewing corporate sustainability performance measurement through the lens of a SOSE perspective.

Traditional systems engineering approaches highlight the need for defining initial requirements as much as possible and can provide insight on the structure and content of a corporate SPMS. However, a SOSE perspective draws attention to challenges that might otherwise be overlooked. For example, there is a need for increased research on processes that deal with emergence in corporate sustainability, assessment systems to guide the ongoing evolution of the SPMS, composite indices to evaluate the overall progress of the corporation towards its sustainability goals, trade-off criteria to address conflicting sustainability objectives, and criteria to identify the basic characteristics of a sustainable corporation. A SOSE perspective can help inform academics and practitioners as they seek to address these challenges.

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