INTEGRATION OF SUSTAINABILITY INDICATORS AND THE VIABLE SYSTEM MODEL TOWARD A SYSTEMIC SUSTAINABILITY ASSESSMENT METHODOLOGY

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ABSTRACT

Reports on the progress of sustainability initiatives in industrial practice and academic research have increased over the past several decades, but organizations are still faced with challenges in defining what sustainability means to them, in assessing their sustainability performance, and in making decisions that allow them to develop as sustainable systems. The developmental milestones of sustainability are consistent with the post-normal versus traditional science, where transdisciplinary and policy/action research are among the important approaches to be added to traditional analysis. This shift requires a new perspective to look at the problem at hand: we are no longer considering a group of users with common and self-interested goals when defining the scope of sustainability studies. This new perspective, in turn, requires sustainability indicators that can capture largely diverse but relevant measurements to completely represent the different perspectives that must be fulfilled, as well as requiring new methodologies that focus on heuristics, systemic stability, control, and feedback, versus traditional optimization for mechanistic problems. The presented research attempts to build upon an established connection between sustainability and viability, i.e., the Viable System Model offers a framework to map the self-adapting mechanisms that allow a system to cope with its internal and external sustainability challenges. These capabilities can help the organization reach its sustainability goals. A sustainability assessment model that integrates both sustainability indicators and Viable System Model methodologies has been developed and is presented here. This model presents an effort towards integrated assessment, with a focus on dynamics, control and feedback.

Key words: Sustainability assessment, sustainability indicators, Viable System Model, integrated assessment

INTRODUCTION

Sustainability has been declared an interdisciplinary, multidisciplinary, and most recently, transdisciplinary (Funtowicz & Funtowicz, 2000; Sala, Farioli, & Zamagni, 2012) issue. Approaches to such a problem solving paradigm requires critical value-judgement functions, in addition to traditional and normal scientific approaches (Funtowicz & Funtowicz, 2000; Sala, Ciuffo, & Nijkamp, 2015). Due to its vague definition, sustainable development has faced many criticisms regarding its interpretation and implementation capacities. Sustainable development, defined by the UN in its Brundtland report, is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987). This definition has led to recognized shortcomings, sometimes termed “green capitalism”

(Springett & Luke, 2005, p. 232), which is seen as an oxymoron (Redclift, 2006), due to its contradicting and mutually exclusive economic goals. Value-judgements and testing of assumptions have been desperately called upon more than ever, and therefore, methodologies that can incorporate these functions have also emerged, especially within the systems thinking realm.

Sustainability assessment is directly influenced by the background assumptions, interpretations, and solution implementations for the problems at hand (Sala et al., 2012; Waas et al., 2014). Besides the technical sophistication required to assess sustainability, the ability to address holism, synergistics (Terenzi, 2005), modeling ability (Kates et al., 2001), policy-based solutions (Sala et al., 2015), and many other non-traditional factors needs to be integrated into sustainability assessment. Thus, adopting a revolutionary set of indicators that can take these factors into account is paramount.

A substantial number of studies have established the linkage between sustainability and viability, not only on conceptual levels (Espinosa, Harnden, & Walker, 2008; Terenzi, 2005), but also on methodological levels (Panagiotakopoulos, Espinosa, & Walker, 2016; Schwaninger, 2008). The underlying assumptions to integrate the Viable System Model into sustainability assessment have been substantiated and, therefore, open up promising opportunities to contribute to the quest of tackling present sustainability issues. This paper builds on the approaches seen in sustainability assessment such as sustainability indicators (SI) (Singh, Murty, Gupta, & Dikshit, 2009), life cycle thinking (Sala, Farioli, & Zamagni, 2013), and complexity modeling (Espinosa & Porter, 2011; Schwaninger & Ríos, 2008) to create a conceptual model for integration of these approaches and the Viable System Model. The conceptual model shows how the Viable System Model can accommodate from simple approaches, such as individual indicator approaches, to more complex approaches, such as composite indicators and life cycle analysis. In addition, the sustainability assessment model presented here emphasizes the urgent need for use of value-judgements, action-based research, and transformative research via control and feedback mechanisms – all of which can be incorporated into the Viable System Model.

EMERGING CONCEPTS

Sustainability Indicators

The Triple Bottom Line (TBL) approach (Elkington, 1998) has been accepted as a universal quantification of sustainability. However, ontological and epistemological development of sustainability demands answers to questions such as what is to be sustained? (Sala et al., 2012), where should resource preservation and exploitation take place in an equitable manner yet still meet global production demands? (Hornborg, 2003), and who are the stakeholders to be included in the phases of sustainability development and assessment? (Davidson, 2014; Hornborg, 2003; Waas et al., 2014). Such questions directly influence the creation, selection, method of measurement, and interpretation of SI (Sala et al., 2015; Waas et al., 2014). SI must consider the interactions between factors from both the conceptual dimension, e.g., worldviews and values, and the physical dimension, e.g., people and physical resources. This requires an overarching approach that can sufficiently and holistically account for relevant situated knowledge, standpoint values, practical implementation, and transformative potentials (Espinosa et al., 2008; Sala et al., 2012).

Emerging SI at the national, institutional, and organizational levels assist organizations and analysts in performing sustainability assessment through various standardized reporting methods and platforms (Parris & Kates, 2003). For example, the Global Reporting Initiative (GRI) has provided a comprehensive list of indicators as well as a methodology to select “material aspects,” or “matters that are really critical in order to achieve the organization’s goals and manage its impact on society” (GRI, 2013, p. 3), for meaningful and salient reporting purposes (Parris & Kates, 2003). This movement has helped improve many reporting objectives, such as *completeness*, *credibility*, *inclusiveness*, and providing *feedback* mechanisms. However, whether the organization has the capacities to interpret the feedback information in a fruitful way, and whether the interpretation is based on the “right” sustainability perspectives – those that meet *legitimacy*, *salience*, and *credibility* criteria (Parris & Kates, 2003), or the combination of which – would require other tool sets that incorporate sophisticated value judgement functions (Espinosa et al., 2008, p. 637; Parris & Kates, 2003, p. 582).

The reporting movement is attractive and necessary, as it is based on strong theoretical backgrounds, among which are Institutional Theory, where institutionalization of sustainability practices creates pressure on organizations to adopt sustainability thinking, and Stakeholder Theory (Freeman, 1984), where sustainability has become a driver for satisfying stakeholder and shareholder needs (Montiel & Delgado-Ceballos, 2014). These two examples for theoretical explanation of firms’ adoption of sustainability place emphasis on the external factors, e.g., stakeholders, shareholders, and competitors, whose analytical capabilities have not been equally developed, especially among entities of different sizes and industries. Other theories focus on the internal capacities of organizations. The Natural Resource-based View (Hart, 1995) is most commonly applied by firms at the beginning of their sustainability journeys, possibly because it is based on the traditional resource-based view that has always been the focus of firms. Firms’ abilities to maintain, accumulate, distribute, account for, and intervene if necessary with its resources (human, material, technological, etc.) are vital for ensuring internal flow.

Measuring management approaches, rather than sustainability outcomes, in the form of sustainability indicators have seen increasing usage (GRI, 2013; RobecoSAM, 2015; Walls, Phan, & Berrone, 2011). But, the questions remain: How do firms know the connection between what structure of management, i.e., roles and responsibilities, is to be adopted? and How do their attributes relate to sustainability improvement? In addition, in order to provide useful insights, interpretation of sustainability outcomes, such as emissions of greenhouse gases (GHGs) and number of fatalities, requires benchmarking (Sala et al., 2015; Waas et al., 2014), external control mechanisms, and the use of higher order language (Terenzi, 2005), which sustainability science is still struggling to define (Kates et al., 2001); hence resulting in ineffective implementations.

Composite indicators have seen increasing utilization in sustainability assessment. Using composite indicators can significantly reduce the number of individual indicators, effectively summarize the data, and provide a convenient option to calculate sustainability scores and to benchmark performance (OECD, 2008). Disadvantages of composite indicators lie mostly in complications rising from, or lack of consideration for, policy-based implementation (OECD, 2008; Sébastien & Bauler, 2013), further emphasizing the need to address the factors holistically. It is especially critical to identify the stakeholders that would directly or indirectly affect the feasibility of implementing solutions.

Epistemology of Sustainability – View from the Viable System Model

The above concerns for organizations are among the "core questions" of sustainability science (Kates et al., 2001). The main premise of sustainability is based on the interactions between different factors and actors within the nature-society environment. Therefore, the first core question of sustainability science focuses on developing tools to incorporate known *interactions, time lags,* and *inertia* into current nature-society models (Kates et al., 2001; Sala et al., 2012). The second core question is concerned with the ability to *predict* future outcomes based on current trends of consumption and population to establish linkages between human behaviors and sustainability (Kates et al., 2001). The third core question aims at establishing *patterns* of environmental changes based on certain geographical areas, ecosystems, and human livelihoods and, therefore, establishing the causal links between the nature-society conditions to secure equity and specific input factors such as worldviews and approaches (Baumgärtner & Quaas, 2010; Borland & Lindgreen, 2013; Kates et al., 2001). Contributing to sustainability epistemology is the quest to establish system *boundaries* and *limits*. These boundaries and limits, when well-defined, can serve at least two purposes – providing evidence for both the cognitive and constitutive values to guide sustainability practices and sustainability science, and creating practical solutions to current sustainability problems. Lastly, the transdisciplinary and transformational functions (Borland & Lindgreen, 2013; Sala et al., 2012) address setting up the problem solutions through an incentive structure that can help guide different actors, e.g., markets, operational systems, and monitoring systems, to achieve overall sustainability goals.

Progress has been made to account for the interactions among sustainability factors, e.g., how the social and environmental aspects would affect a firm's economic performance (Darnall & Edwards, 2006; Hutchins & Sutherland, 2008; Orlitzky, Schmidt, & Rynes, 2003; Zhang & Haapala, 2011). However, the challenge of identifying the intrinsic values of these results calls for critical evaluation of the background assumptions, such as those of the anthropocentric and ecocentric views (Borland & Lindgreen, 2013). For example, how do firms make informed and justifiable decisions when choosing to invest in new technologies to improve productivity and, hence, satisfying society's demands, or community developments, such as building schools and social programs, given that social equity has already received total management buy-in? Thus, the SI approach requires a major overhaul to improve the implementation phase. Soft Systems Thinking (Checkland, 1983, 1985) is a well-established methodology to better identify both the context and content structures of the system, especially more complex systems, in order to proceed with understanding and applying system interventions. Critical Systems Thinking (Jackson, 2001) improves upon traditional systems approaches by providing methods for testing and evaluating background assumptions. Both approaches are consistent with the normative function of sustainability (Sala et al., 2012) and of System 5 (S5) of the Viable System Model (Espinosa et al., 2008). Integration of the Viable System Model and different complex system approaches, such as complex adaptive systems (Espinosa & Porter, 2011) and system dynamics (Schwaninger & Ríos, 2008), has been proposed.

All systems approaches require establishing the boundaries of the system in focus (SIF). However, sufficient consideration for the environmental component is one of the special characteristics of the Viable System Model. The Viable System Model calls not only for the recognition of the relevant environment components, but also for the interactions within environmental components and between the environment and the SIF. This creates "a series of cognitive spaces, in dynamic relations with one another and the global environment" (Harnden, 1990, p. 294), which coincides with the intrinsic goals of sustainability. Structure-wise, the Viable System Model provides its *recursiveness* property, which exists between different levels of a system and must be accounted for (Beer, 1995). Once the necessary system components (contents) are revealed, the efforts of stabilizing and managing internal and external conflicts (contexts) can be carried out heuristically (Terenzi, 2005). Establishing consensual flow, or continuous agreement between stakeholders, is another powerful capability of the Viable System Model (Harnden, 1990). As the interpretation, approach, and implementation of sustainability studies rely heavily on the value-laden approach (Waas et al., 2014), modeling systemic sustainability requires incorporation of "structural congruence between observers" (Harnden, 1990, p. 295), so that consensuality and coordination can thrive. This is the function of System 2 (S2) of the Viable System Model (Harnden, 1990). Moreover, it has been argued that a system cannot achieve sustainability without achieving viability (Terenzi, 2005).

Lags, inertia, and other causes of systemic variation can be accounted for using statistical approaches, e.g., time-series or spatial analysis. However, these methods have limitations and not all firms have these capacities, especially when data collection presents a challenge. To cope with such limitations, self-awareness, self-adaptation, and independence within a specific environment are among the capacities that firms can incorporate in the design of their organizational structure to detect and absorb the impacts of time and geographical changes. These are features of the Viable System Model's optimal design (Beer, 1995). Each of the above capacities requires official and specific system components that act as the champions for their specific responsibilities. More specifically, System 3 (S3) and S2 facilitate distribution of resources and regulations, coordination, and optimization functions to ensure essential needs of the operational system – System 1 (S1) – are met (Beer, 1995). With assistance of the auditing function of System 3* (S3*) and the capacities to handle environmental inputs at the lower management level (S1), S3 ensures the internal system is supported and its performance accounted for (Beer, 1995). In addition, predicting future outcomes is a specialized function of System 4 (S4), which forms a coupling system with S3 to closely monitor systemic lags, inertia, and common-cause and special-cause variation, and to balance the inside-outside needs and perspectives of relevant stakeholders. There are myriad features of Viable System Model that are compatible with supporting knowledge inquiry, assessment, and implementation of sustainability, which makes the model an attractive candidate for facilitating true transdisciplinary and transformative approach.

The objectives of "viability" – the ability of an organization to maintain its characteristics, such as *identity, self-awareness, self-repair,* and *recursivity* (Beer, 1995, p. 17) – have been shown to be applicable to the model of sustainability (Espinosa et al., 2008; Espinosa & Porter, 2011; Leonard, 2008; Schwaninger, 2008). The VSM is developed and based on the Law of Requisite Variety (LRV) (Ashby, 1958), which states that "the variety in the outcomes, if minimal, can be decreased further only by a corresponding increase in that of the response (R)"; hence this increased variety is necessary, or "requisite." This leads to Beer's call for the Design for Freedom concept (Beer, 1993), which emphasizes the importance of providing capacities to lower system levels, as well as reducing information loads in the appropriate management channels, so that an optimal design, as discussed in detail below, can be achieved. If sustainability performance is measured at every system level and sustainability outcomes are generated by activities and interactions throughout the sub-systems, then by deductive reasoning, outcomes and interactions at the higher system levels, e.g., corporations, cities, or countries, can be accounted for. Previous work that applied the Viable System Model to implement sustainability initiatives at different system levels, e.g., communities (Leonard, 2008; Walker & Espinosa, 2013) and large corporations (Walker, 1998), have shown successful planning or implementation outcomes.

Homomorphism, Isomorphism, and Control Mechanism for Viability

The "many-to-one" mapping between different systems is common in abstract algebra, cybernetics, and other fields. In operations research, the ability to establish homomorphic structures was a revolutionary step, as complex human systems can now be modeled and simplified. Two binary structures, namely $(S,*)$ and $(S',*')$ are homomorphic if and only if $\emptyset(x * y) = \emptyset(x) *' \emptyset(y)$, where $\emptyset$ is the many-to-one function mapping S to S', and $*$ and $*'$ are binary operations. In other words, despite being two separate operations that may belong to two different systems, the two operations $*$ and $*'$ can be designed to produce the same type of outputs through their own transformations. For example, the "production control" function might be designed differently across different organizations, with different numbers of operators and machines, but each serves the same purpose, and the high-level schematic representation of the transformations of production control, e.g., turning work orders into work schedules, can take the same form. Extending this formulation across different systemic structures, a universal schematic representation can be developed, where each universal representation can be said to be *isomorphic* – having the same structure by satisfying the one-to-one, onto, homomorphism, and scalar properties. Moreover, an "optimal design" can be developed by taking the forms of structures that are known to have achieved the desired efficiency. Beer took the physiological design of the human body to create this optimal representation, called the Viable System Model, which any other organizational structures can be mapped onto.

Beer has shown that different management structures, which possess countless numbers of operations, can be successfully mapped onto the Viable System Model by using the concept of homomorphism (Beer, 1972, 1995). Hence, interventions made on the Viable System Model's systemic structure can be applied to other systems by using the same concept. The interventions are based on the simple form of control mechanism (Beer, 1959) that adopts the Black Box with Feedback concept (Ashby, 1958; Beer, 1959) to link the Real Life machine and the analyst's Control Mechanism of that machine. In real life, actual factors, such as labor and material inputs and management approach, can be approximated with a set of mathematical functions (A). Structuring the set A to represent the production line creates the traditional Operations Model (OM), which is refined and updated as information from actual factors is collected. Projection of actual production based on the OM are contained in the "plan." If the set B contains the approximated actual production, then the control mechanism of the production system can be measured by maintaining an approximately constant r, which is the correlation between A and B. The control challenge has been shown successfully resolved if r is kept invariant by feeding its value to the transformation from the OR model to the plan (Beer, 1959). This cellular model (Figure 1) represents the simplest form of S1, S2, and S3 within the Viable System Model.

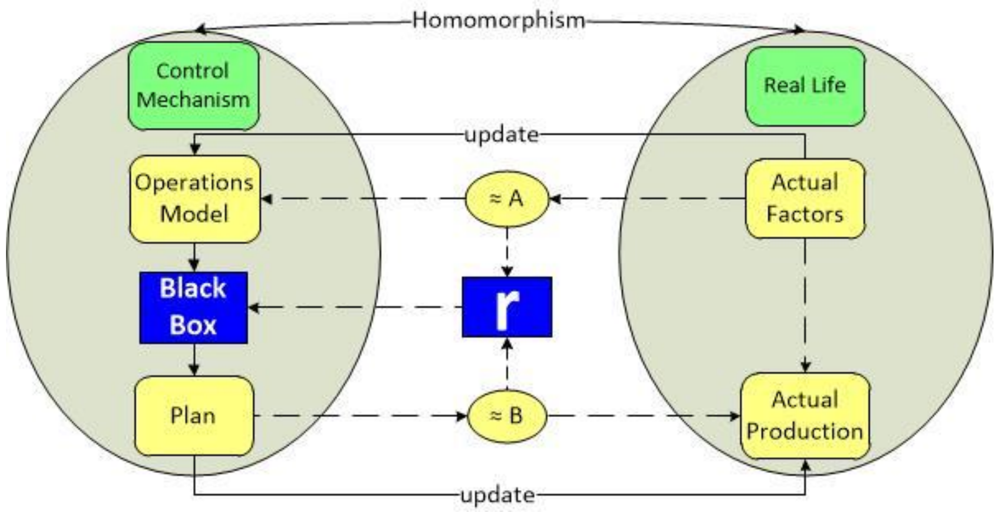

Figure 1. Modified Real Life - Control Mechanism Model (Beer, 1959)

Specifically, after the measures of "actuality" (AC) are transduced, at least three quantities can be measured for self-awareness purposes: productivity (PR), latency (L), and performance (P) (Beer, 1972). If capability (C) is what the OR plan suggests based on the existing performance, and if potentiality (PO) is a value within management goals, then PR=C/AC; L=PO/C; and P=PR*L. The inverse of PR and L can also be used to ensure the numerators always take the smaller value. Information collected at the lower systems can then be transferred to S4 and S5, where environmental factors can be incorporated and the new set of C and PO values can be delivered back to the lower systems for implementation (self-adaptation). This completes the description of the Viable System Model mechanism. Step-by-step guides for mapping any organizational structure onto the Viable System Model by identifying different operational functions, roles, connectivity, and management levels within each organization, have been extensively provided (Beer, 1995; Panagiotakopoulos et al., 2016; Walker, 1998).

Top-down and Bottom-up Assessment

"Variety" is defined by the system's possible "states" (Beer, 1995) or by the number of distinct elements in the system (Ashby, 1958). A "state" indicates as whether the resulting change serves the "purpose of the system" (Beer, 1995). Therefore, being able to recognize the various states of the system can prepare management in coping with changes, and facilitate feedback mechanisms. For instance, if variety represents the number of states to choose from within a set of options, variety would be equivalent to the logarithm to the base two of the number of options (Ashby, 1958; Beer, 1995). If a decision contains a combination of options governed by their own constraints, e.g., choosing from among *x* number of fuel types available from *y* suppliers, then the total variety for a combination of xy options would be $V(xy) = log_2 xy = log_2 x + log_2 y = V(x) + V(y)$.

The language used to describe variety has also been addressed by Beer (Beer, 1959, 1995). It is almost impossible, and not of great use, to measure the exact states of the system and its subsystems. However, using a "higher language", to compare and draw conclusions on the reduction or increase of variety, or using "ordinal" data, is one of the most innovative contribution cybernetics has offered to tackle complex systems (Beer, 1959). The use of binary numbers, checklists, or categorization matrixes are examples of how the "higher language" can reduce the challenge of variety immensely.

Requisite Variety also applies to uncertainty. To demonstrate reduction of requisite variety, Beer used an example of applying a logarithmic base two (corresponding to a binary decision) to reduce a variety of eight, corresponding to a decision to make one product using one of eight machines, to three ($2^3 = 8$); so the challenge remains with having a standardized decision making process to assign a machine every time an order arrives (Beer, 1972).

There are multiple decision making methods. Among the previously reported SI methods, Principle Component Analysis/Factor Analysis (PCA/FA) is among the most commonly used approaches to evaluate the significant factors that contribute to measurement variation. PCA/FA groups factors into composite variables called "principle components" (OECD, 2008). The principle components are considered driving factors and used to construct a composite sustainability index (Parris & Kates, 2003). Each index consists of the core factors that form the primary structure of the data. In addition, PCA results can be used to compute the total sustainability performance index (SPI) of a firm (OECD, 2008). By detecting the driving factors of sustainability using empirical evidence and top-down approaches, such as PCA/FA, management can gain a preliminary sketch of reality related to sustainability.

Based on the concepts of homomorphism and optimal design achieved through the Viable System Model, a set of organization theories derived by Beer (1995) can be used to further improve the application of the Viable System Model on organizational improvements. This set of organizational theories includes the four principles of organization, the three axioms of management, and the law of cohesion (Beer, 1995). Using these theories, sustainability assessment key performance indicators (KPIs) can be defined and evaluated from the standpoint and bottom-up views, which has been the emphasis of the sustainability movement to include stakeholders such as employees and minority groups, whose voices are often overlooked (Sala et al., 2015; Waas et al., 2014).

Beer's *First Principle of Organization* states that "managerial, operational, and environmental varieties, diffusing through an institutional system, tend to equate; they should be designed to do so with minimum damage to people and to cost." This statement can be considered an overarching principle for guiding the implementation of sustainability. Basic ethical and operational improvements designed for organizations, e.g., providing adequate training and worker compensation, should be met. In addition, depending on the specific industry and region, firms can improve their competitiveness by meeting and exceeding industry and regional standards.

Beer's *Second Principle of Organization* states that "the four directional channels carrying information between the management unit, the operation, and the environment must each have a higher capacity to transmit a given amount of information relevant to variety selection in a given time than the originating subsystem has to generate it in that time." The principle focuses on the rate of data transmission and the communication technologies in use. From a sustainability perspective, the challenge of measuring direct and indirect inputs and outputs is partially caused by the delays in a firm's realization of the benefits and materialization of sustainability improvement implementations, and vice versa. In addition, different stakeholders have their own capacities, intentional or not, of transmitting their own sustainability-related data and information. These capacity limits increase uncertainty in capturing on-time information across different sub-systems and their environments. Resulting delays create oscillations and significantly hamper efforts to find solutions for the last three sustainability core questions (Kates, 2011).

The *Third Principle of Organization* states, "Wherever the information carried on a channel capable of distinguishing a given variety crosses a boundary, it undergoes transduction; the variety of the transducer must be at least equivalent to the variety of the channel." This principle focuses on the system's transducers, which relate to the system's ability to preserve variety, whether the variety has been attenuated or amplified (Beer, 1972). Although transducers for sustainability in most management systems are insufficient, e.g., difficulty interpreting impacts of current safety practices or materials, progress to classify and fully capture sustainability-related variety from S1 has been made. For example, many organizations have established safety teams to identify safety failures and implement training programs and healthy workplace initiatives. Therefore, actual capacities of existing management transducers can be evaluated against an organization's set of prioritized sustainability issues.

While the Second and Third Principles of Organization deal with the rate and volume of information being processed, the *Fourth Principle of Organization* deals with frequency, stating, "The operation of the first three principles must be cyclically maintained through time without hiatus or lags." S2 has a specific responsibility to ensure the status of daily activities are captured and that solutions are delivered. For example, it must ensure there is sufficient PPE and other safety supplies, and that the work schedule incorporates employee paid vacation and sick leave. S3* conducts compliance audits and study groups, while S3, S4, and S5 process accountability information sent from the lower systems to provide the lower systems adequate and timely resources and rules. These common practices can be explained by the LRV to show an efficient control mechanism that should not be taken for granted; hence, management indicators for sustainability performance need to account for whether or not sufficient variety-absorbing functions are in place.

In addition to the four principles of organization, the *First Axiom of Management* proposed by Beer can be applied to organizational sustainability assessment. It states, "The sum of horizontal variety disposed by all the operational elements equals the sum of vertical variety disposed on the six vertical components of corporate cohesion." The six different systemic functions – environment, inter-operations, audits, accountability, rules and regulations, and anti-oscillation – focus on counteracting each source of variety within the operations system (S1) and can only do so by following the LRV. The first axiom by no means has been achieved even by the most sustainable organizations. Due to their breadth, the environmental elements of a system can generate unlimited sources variety, e.g., variety in material or supplier selection. This variety is especially compounded under the broad scope of sustainability assessment. Efforts to identify and measure environmental variety is still underway by sustainability researchers via discovering sustainable options and identifying hazards. Matching the complexity of current operational systems with each of the six vertical components of the Viable System Model in terms of one specific sustainability issue could reveal where management efforts need to be concentrated.

The *Second Axiom of Management* ensures variety disposed by S3 is matched by the requisite variety of S4, and *The Third Axiom of Management* ensures variety disposed by S4 after the application of the second axiom is matched by requisite variety of S5. This control mechanism and balance design approach ensures that upper-level management is self-aware of the issues that are not recognized or resolved at the lower levels. In addition, it ensures the total variety disposed by the metasystem is equal to that of S3 in order to provide requisite variety that balances the total variety of S1 (from the first axiom).

The combination of different operation systems creates a level of recursion, recursion “x.” The sum of all the variety of S1 that is recognized by S3 in recursion “x” can be balanced by the sum of the metasystems of recursion “y.” This turns the metasystems of recursion “y” into S1s of the lower recursion. This can simply be done by applying the first axiom. This is the *Law of Cohesion* coined by Beer, and it is helpful in understanding the nature of management levels, drawing effective system boundaries, and accounting for the necessary variety generated by the different levels of recursion. The higher the management level, the more effects from the Law of Cohesion can be recognized.

SYSTEMIC SUSTAINABILITY ASSESSMENT MODEL

The proposed Sustainability System Assessment Model (Figure 2) integrates the concepts of SI and the Viable System Model. The five previously-defined systems are presented, with S2 as the coordination channel (5). The components numbered in parentheses represent the six vertical channels ((1)-(6)) and horizontal channels of S1 (I) based on Beer’s *First Axiom of Management*. The components labeled from *a* though *f* represent necessary calculations to evaluate sustainability performance and system stability, based on the Real Life-Control Mechanism model. The indicators that fall under the oval labeled Control Mechanism are suggested from the SI method, taking both the bottom-up and top-down approaches, and assuming S4 has already performed top-down analysis to reduce the variety of SIs. The environment contains all external factors that contribute to a firm’s sustainability performance. The majority of the suggested indictors have been adopted from GRI and literature, while others come from interpretations of Beer’s four principles and his first axiom. Suggested indicators can be in quantitative, binary, or categorical forms; tailored to the type of information the organization needs.

Demand for products and services directly dictates the number of operational activities, which, depending on the firm’s sustainability approach, generates impacts that directly affect the community (people) and habitats (nature). Component S1-2-3 is responsible for the “inside-and-now” of the firm (Beer, 1972), where a set of prioritized sustainability issues are tracked (Actuality), and the quantities productivity (PR), latency (L), and performance (P) for each indicator are measured and compared to previously measured indicator values (Beer, 1972). Component S3-4-5 is responsible for the “outside-and-then” (Beer, 1972), where more sophisticated methods are in place to capture what S1-2-3 is unable to. S3-4-5 is also responsible for providing new rules, regulations, and resources, and setting new limits for capacity (C) and potentiality (PO) values for each indicator in order to adapt with external factors.

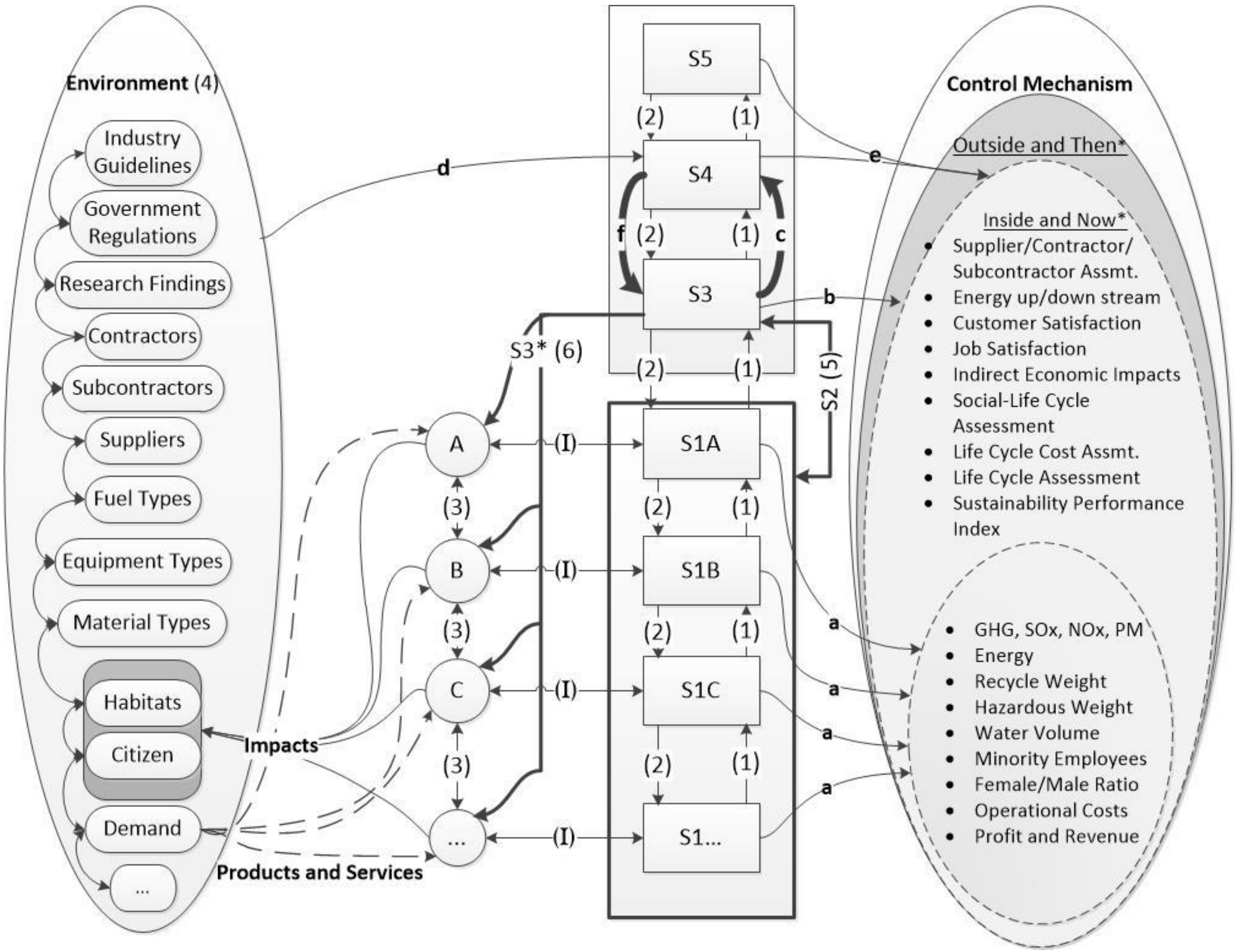

Figure 2. Integrated Sustainability System Assessment Model using the Viable System Model Framework

Indicators on Management Approaches (MAIs)

Information Flow – Principles 1 through 4

Based on the first four principles of the Viable System Model, a set of indicators addressing communication effectiveness and overall organizational efforts to minimize impacts is suggested in Table 1.

Principle	Sustainability Interpretation	Suggested MAIs
1	Minimizing Damage to Resources and People	Percent of employees who receive training; rating of transitioning programs; investment in employee wellness; number of benefits offered

2	Communication Technologies	Use of real-time monitoring technologies; fast and reliable communication technologies
3	Data Handling and Processing Capabilities	Ability to measure up/downstream energy and environmental impacts; use of hazardous material detection technologies; use of injury warning technologies
4	Effective Coordination, Audits, Monitoring, and Control	Number of sustainability assessments per year; number of environmental compliance audits per year; number of job satisfaction studies per year; responsiveness of helplines for employees

Table 1. Suggested MAIs for Sustainability Communication Effectiveness

System 1 (S1) Capacity – Axiom 1

The ability of S1 to balance all input factors generated from the six vertical components ((1) through (6)) is determined by the variety generated from the horizontal channels (I). This is consistent with Beer's Design for Freedom concept, which encourages firms to equip operational systems with enough capacities to absorb and resolve its input factors. Equivalently, the ability of higher systems to counteract variety generated from S1 is also included in the first axiom. Table 2 gives examples of MAIs to determine S1 capacities to balance the variety of the six vertical components. For each variety component, indicators are generated based on assessment of the organization's prevention, implementation, and compliance methods (Walls et al., 2011).

Variety Components	Sustainability Interpretation	Suggested MAIs
(1) Resource bargain	Requests for resources are sufficiently provided.	Environmental impacts of resources and materials provided; job satisfaction results; number of safety and environmental compliance trainings
(2) Interventions and regulations	Sustainability related rules and regulations exist and are communicated effectively.	Regulations and incentives exist to address applicable sustainability issues; adoption of up-to-date regulations and incentives relevant to the organization
(3) Operational linkages	Physical transactions of materials, parts, personnel, etc., between each operation should be carried out in the most efficient ways that result in the least "costs."	Assessment of facility layout; assessment of distribution network; applicable trainings available for each operation/task

(4) Environment	Organizations are aware of the main environmental factors that influence sustainability performance, and the ability to capture their varieties	Use of materiality assessment (GRI, 2013); customer satisfaction surveys; number of consumer complaints; use of sustainable contractors and subcontractors list; use of green designs, standards, and materials; approaches to protect natural habitats and consumers; investment in sustainability research
(5) S2 – anti-oscillation	Available resources, including rules regulations, are accessible to all workers. Communication between higher management and shop floor managers is effective with minimum delays.	Sufficient PPE is provided for all tasks and personnel; environmental and safety rules and regulations are accessible and posted; hazardous materials are properly collected and handled; environmentally friendly equipment, fuel, and materials are used.
(6) S3* - Audit	Audit channels should be capable of helping upper-level management uncover the vital information that is suppressed by S2, in order to realistically assess S1's status.	Number of violations during safety and environmental compliance audits; number of audits and risk assessments conducted per month

Table 2. Suggested MAIs for Balancing System Variety

Control Mechanism – Measuring Actuality, Capacity, and Potentiality

"Inside-and-Now" consists of the suggested Sustainability Key Performance Indicators (SKPIs) (Actuality) for each activity tracked by S1 (a), while the rest can be tracked by S3 (b). All S1 subsystems should compute their Productivity (PR_t), Latency (L_t), and Performance (P_t) values, using benchmarking values Capability (C_{t-1}) and Potentiality (PO_{t-1}) that S4 and S5 have either proposed or imposed during previous assessments. S3 is responsible for compiling the total impacts and compute L_t and P_t for all S1s' SKPIs. This feedback loop creates the necessary goal-seeking mechanism for the internal systems to perform self-adaptation. This completes the control mechanism for the "Inside-and-Now" loop.

The "Outside-and-Then" loop starts at calculation (d) (PCA/FA or similar methods), where S4 performs a new assessment iteration. The outputs of the S4 assessment is a new set of proposed SKPIs (e), taking into account S5's normative values and goals. Setting new C_t and PO_t values, however, requires iterative feedback loops between S3 and S4 (c) and (f), to ensure C_t and PO_t set realistic goals to be attained by the lower systems. This completes the control mechanism for the whole Viable System Model.

Equations 1-3 summarize the control mechanism for each SKPI*i:*

$$PR_{ti} = C_{(t-1)i}/SKPI_{ti} \tag{1}$$

$$L_{ti} = PO_{(t-1)i}/C_{(t-1)i} \tag{2}$$

$$P_{ti} = PR_{ti} * L_{ti} = \frac{C_{(t-1)i}}{SKPI_{ti}} * \frac{PO_{(t-1)i}}{C_{(t-1)i}} = PO_{(t-1)i}/SKPI_{ti} \tag{3}$$

DISCUSSION AND CONCLUSIONS

Design for Freedom – Empowering Lower Systems

Beer was clearly against micro-management practice as a form of monitoring and control (Beer, 1993). The "brain of the firm" should not be bogged down with volumes of day-to-day, minor issues where, with capacities, resources, and an efficiently designed structure, these issues can be resolved at the lowest level possible. The micro-management problem remains in today's management system, while its counter-argument can be explained using the logic of Viable System Model. Since one challenge of sustainability management is its vagueness, it can create more risk, either with management decisions to turn their backs or with the emergence of micro-management due to lack of understanding and control tools. Therefore, knowing the "what" to measure and control and the "how" to control offers tremendous implementation relief for higher management, and helps to place responsibilities where they are most appropriate within the various levels of an organization.

Recognizing Recursive System

Perhaps the concept of organizational recursiveness has been taken for granted, as not many organizational diagnostic tools have questioned whether the current structure can ensure efficiency, nor how it can be ensured. The Viable System Model relies heavily on recognizing the different systems and their levels, as well as accounting for their responsibilities. Tools can be developed to assist organizations in recognizing the structure of their systems so that they can be incorporated in the Viable System Model to reveal discrepancies in variety distributions. Examples of these tools include checklists or questionnaires, developed from a carefully chosen list of MAIs.

Principle Component Analysis – Low Variety Attenuator

Besides being one of the most common methods to compute SI (OECD, 2008), PCA/FA fits within the "variety attenuator" scheme of the Viable System Model, which makes it a powerful tool when applied between the system and its environment. The underlying purpose of PCA/FA is to capture indicators with the highest variation (OECD, 2008), which, in turn, contributes to the total variation of a firm's sustainability outputs. While it is a generalization to consider attenuating all indicators that remain approximately constant, it is more realistic to do so, as if an SKPI's outputs are similar among firms, it can indicate either (1) technologies are not yet available to change certain threshold for the specific indicator, or (2) the standard practice has been matured and therefore no longer requires firms to invest in changing current practice. The sustainability assessment model presented here also requires firms to perform bottom-up assessment and standpoint value judgements, e.g., life cycle analysis and MAIs, to determine the relevant factors. The bottom-up and top-down interactions to fully assess organizational sustainability represent the S3-S4 and the SIF-environment interactions.

System Dynamics Model for SPI

One of the benefits of simulation include its predictability power. System dynamics models can be developed to predict SPI values over time by using the proposed input C and PO values for the indicators that make up the composite variables of SPI. Once an organization has completed collecting information on the SKPIs that *can* be included in the PCA/FA model, as well as the mechanisms of PCA/FA and SPI, performing sustainability assessment at each iteration can be simplified with the advantage of simulation accessible at hand. Therefore, integration of the Viable System Model and system dynamics approach, which has been demonstrated conceptually (Schwaninger & Ríos, 2008), presents opportunities to include simulation capacities in the current sustainability assessment model.

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