Morphological Analysis of General System-Environment Complexes: Representation and Application.

Abstract

Systems and their environments must be understood in an integrated manner since any changes in the systems will affect their environments and vice-versa in the ubiquitous Open Systems. Existing studies classify systems based on the diversity of their interactions and the systems' responses to changes in their environments. However, the uses of such classifications are limited. We attempt to address this limitation by using Morphological Analysis (MA) to identify, represent, and characterise the general System-Environment Complex (SEC) and its components. The latter, called 'dimensions', and their respective manifestations, termed 'variants', are integrated into the MA representation to enable a holistic understanding of SECs in terms of six dimensions and 101 variants. The resultant representation and characterisation will help researchers identify potential research opportunities, demonstrated through the construction of a Variants Intersection Matrix and help develop practical principles for system design and evaluation.

Keywords

System-Environment Complex, General Systems Theory, Morphological Analysis, System Design and Evaluation, Variants Intersection Matrix

Introduction

The Systems Thinking body of knowledge helps us understand our world of increasing interconnectivity, complexity and uncertainty. The ubiquitous occurrences of bad surprises, which are unintended, unanticipated, and undesired consequences of problem-solving and decision-making exercises, serve as a strong justification for adopting systems perspectives of the world around us in the problem-solving situations we face. Several authors have called for using the Systems Approach rather than silos thinking or reductionist approaches in solving interconnected and messy problems (Jackson & Sambo, 2020; Siriram, 2012).

The Systems Approach enables problem solvers to anticipate complex and emergent systems' behaviours (Chen, 1975; Clayton & Radcliffe, 2018; Jackson et al., 2010). What are the antecedents of these complex and emergent behaviours? Both logically and intuitively, a system's internal interactions and those with its environment cause such behaviours (Minati et al., 1998). A system and its environment are inseparable (Ahvenainen et al., 2017) and always interact with/influence each other (Skyttner, 2005; Von Bertalanffy, 1968). Thus, there is a need to understand the systems and their environments (Thompson et al., 2009) and their interactions, all of which are integrated and termed as the System-Environment Complex (SEC).

In this paper, the Morphological Analysis framework (MAF) representation of SECs, presented for the first time, provides a conceptual foundation for understanding SECs in general and adds to the Systems Theory body of knowledge. We also present a schematic diagram of interactions of the major, abstract components of SECs. This generic representation of SECs is applicable across all systems (except transcendental systems) classified by Checkland (1999). Our analytical-synthetic approach enabled by Morphological Analysis involves identifying and characterising the individual components of SECs, namely, inputs, boundary, processes, outputs, feedback, and anticipation, response and control unit, and later integrating the applicable characteristics for gaining a holistic understanding of any SEC. This has both theoretical and practical implications. It could be useful for identifying research opportunities and yield fundamental principles for systems design and evaluation.

System Environment Complex – A Theoretical Background

Bertalanffy (1968, p.55) defined systems as "a complex of interacting elements", which are open to and interact with their respective environments. From this definition, we can understand that

i. a system will always consist of at least two interacting parts (elements),
ii. a system is different and distinct from its environment, and
iii. the system as a whole or some of its parts interacts with the environment.

A few questions that follow are: Firstly, what separates a system from its environment? In reality, we observe many nested systems, such as our human bodies comprising many nested sub-systems. Then, an observer would be necessary to distinguish between a system and its environment, identify the system's purpose, and then contextualize it or set reference frames (Ackoff et al., 2005; Gharajedaghi, 2011).

Secondly, what role does the environment play in the operation of the system? A literature search in the Scopus database with terms such as "system-environment interaction[1]" returned 204 articles,

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[1] Terms such as interchange, interplay, influence, complex, relation, interdependence, association, reaction, interactivity, reciprocity, exchange, link, interrelationship, correspondence, were used in lieu of 'interaction' in the search term "system-environment interaction" to augment identification of literature. Articles that did not pertain to 'Systems Theory' or focus on 'System-Environment Interaction' were filtered out.

of which 20 dealt with Systems Theory. Despite our focus on only Scopus-indexed literature, we could understand the theoretical underpinnings of system-environment interactions. The 20 articles on Systems Theory frequently referred to four seminal works, viz., Bertalanffian General Systems Theory (Bertalanffy, 1950, 1956); Ashby's Theory of Requisite Variety (Ashby, 1991; Ashby & Goldstein, 2011); Wiener's Cybernetic Theory of Feedback (Wiener, 1948, 1949), and Luhmann's theory of Autopoietic Social Systems (Luhmann, 1995; Luhmann et al., 2013). These works on system-environment interactions comprise two streams based on 'operational closure'. When the environment does not instruct the operators of a system, the latter is said to be operationally closed (Maturana & Varela, 1991; Varela et al., 1974a).

Bertalanffy argued that system-environment interactions are aimed at maintaining equilibrium between a system and its environment. This system-environment relation is achieved by feedback from the environment (Valentinov et al., 2017). According to Bertalanffy, systems can exhibit more complexity than their environment (Valentinov, 2012). Ashby's Complexity Theory proposes that a system responds to its environment point by point (Ashby, 1991; Vanderstraeten, 2001). Increased complexity of a system signifies its response to the changes in its environment. On the other hand, Luhmann argued that the system-environment relationship is precarious due to the autonomy the (autopoietic) system enjoys (Valentinov, 2019). He maintained that the complexity of the environment is much more than that of the system. Systems produce their own degrees of freedom due to operational closure and may choose not to react to changes in their environments (Luhmann, 2012; Valentinov, 2017a). In reality, this may not be the case; it is evident that changes in the environment (for example, climate change) have a serious impact on the internal dynamics of various social, including political and economic, systems (Vanderstraeten, 2001).

Luhmann questioned the role of cybernetic feedback in systems attaining their goals in an unchanging environment (Valentinov, 2017b). In reality, since we deal with open systems, it may not be possible to have an unchanging environment. Thus, the role of feedback, including information about the (changes in) environment to ensure that a system will operate in such a way that systemic goals are met, may still be relevant. Although both schools of thought differ in interpreting the nature of system-environment interactions, both acknowledge their existence. Secondly, the need for studying and understanding a system and its environment together for meaningful research and practice justifies our MAF representation.

There are at least a couple of studies on the classification of system-environment interactions. For example, Sutherland (1975) classified systems based on their ability to respond to changes in their environment. Martinelli (2001) classified systems based on the diversity of their system-environment interactions ranging from non-systems to evolutionary systems. We propose MA as an analytic-synthetic approach in which the system's components and its environment are first identified and characterised. Then, plausible combinations of the components' characteristics are integrated to derive representations of existing and possible types of SECs. Hence, our representation differs from existing classifications. While system-environment interactions refer to the overall composite behaviour, an underlying structure influences it. We call that structure as the System-Environment Complex[2] (SEC).

[2] 'Complex', first used in Systems Theory and popularized by Bertalanffy, has a composite meaning. It refers to both, structure (network) and behaviour (interactions), and is appropriate in this context.

Bertalanffy combined Wiener's Cybernetic Theory and Ashby's Complexity Theory to propose a basic model of system-environment interactions, in which the system receives input from its environment, then processes it to generate output to the latter. The system pulls in information about the output as feedback to respond to, or even influence, the changing complexities of the environment guided by the systemic goals (purposes). After Bertalanffy, Hafez (2010) conceived an improved model of system-environment interactions for information inputs. In his conception, a system comprises (a) sensors, which collect information inputs from the environment, (b) controllers, which use the received input information and decide appropriate actions, and (c) effectors, which implement those actions. In this paper, his basic model is expanded into a generic SEC and presented as a schematic diagram in Figure-1, which shows the integration of the connections among its various components (later referred to as dimensions). This representation is the first such attempt to portray SECs in general, comprehensively and graphically. The figure also combines the elements of Concept Maps in it and depicts the general working of SECs with greater resolution than the usual input-process-output-feedback representation.

System-Environment Complex (SEC)

The SEC signifies the non-separability of the system and its environment. The moment a system is defined and contextualised, its environment automatically exists and deserves attention. However, the definition of a system does not define its environment also. The contextualisation merely separates a system from its environment and focuses on the former. The relevant boundary effects the separation. While everything is connected to everything else in this universe (Capra, 2010) and therefore mutual influences are ubiquitous, directly or indirectly, some systems in the environment influence the observed system more than other systems. It is, therefore, the judgement of the observer or the window of perception (Meadows et al., 1972) of the observer that defines the environment that consists of (i) impacted systems, (ii) influential systems, and (iii) involved systems, all of which are called as interested systems (elements) in this study.

INSERT FIGURE – 1 ABOUT HERE

Environment – Inputs, Outputs, and Interested Elements/Systems

Following the general architecture of the SEC proposed by Hafez (2010), it is conceived that inputs to and outputs of a system respectively originate from and reach its environment. Even for complex and nested systems such as ecosystems, the inputs and the outputs are outside the system (Heal et al., 2005). The rate, quality, and type of inputs are controlled by a control unit inside an Anticipation, Response, and Control Unit (ARCU). However, other inputs beyond those determined by, or within the control of, the ARCU may also reach a system from its environment. The outputs of the system either impact or are sensed by other "interested-elements/systems" in the environment. These ARCUs of interested-systems respond to the outputs of the observed system and may influence its inputs. This dynamic interaction between interested systems (in the environment) and the original system is generally concurrent and iterative and happens while the system functions or even sometimes when it does not.

Anticipation, Response, and Control Unit (ARCU)

In an SEC, the inputs to the system are sent to and sensed by its ARCU, whose functions, as its name suggests, are (a) anticipating inputs and outputs (feedback), and determining their variations, (b) responding to the inputs and feedback, and (c) controlling the inputs and processes, and thereby the outputs. The ARCU of a system can be a separate unit (lumped sub-system) inside it or embedded within it in a distributed manner. Some ARCUs may also perform anticipatory functions and sense the changes in the environment and modify the system's processes, inputs, outputs, capabilities, and capacities to avoid or mitigate undesirable results (Rosen, 2012). Table 1 depicts various systems based on Martinelli's classification and their ARCU's functions. The ARCU manipulates the system's response to its environment based on feedback from the internal and external sources and by sensing the environment.

INSERT TABLE – 1 ABOUT HERE

In the ARCU, the anticipation and response function processes the information on input attributes such as rate, quality, nature, frequency and sends decision signals (planned response) to the control unit, which then controls/moderates/regulates the inputs, based on the planned responses. The control unit then sends a refined input to the processor.

Process (Processors or Effectors)

The processors, guided by the system's purpose, then process the refined inputs provided by the control unit of the ARCU. The processor delivers the outputs of the system to its environment. Yet, unintended outputs could also be present in the dynamic interactions between a system and its environment. The ARCU processes the information on the inputs, processes, and outputs, whereas the processor transforms the system's inputs into outputs.

Feedback

Feedback is the information on the intended and unintended outputs that are pulled/pushed into the system. Feedback (Feedforward) can also be sought from uncertain and dynamic inputs and processes (Ramaprasad, 1983). In this conception of the SEC, feedback on the outputs and inputs are captured by external feedback sources (receptors) and the variations in the system's processes are captured by the internal feedback unit. Feedback can be collected on one or many input/output parameters (Ramaprasad, 1983). The purpose of a system can determine the feedback unit's position relative to the input, the process, and the output. Information about water inflow to a dam must be collected if the dam's purpose is to supply water for irrigation or release excess water out while holding minimum mandatory stock. In this scenario, the feedback unit is connected to and obtained from the input and is a part of the input. The above example is also an illustration of a basic feed-forward process, where the information about the environment is used to modify the process of the system before an output is delivered. In this study, we focus on the nature of collection and transmission of feedback and feed-forward mechanisms. Since both are similar, we have not distinguished between them. Also, not all systems are equipped with a feedback unit; for example, static and simple dynamic systems do not have feedback units and receptors.

Boundary

In the SEC, the system is separated from its environment by a boundary, which is defined by the context of the system. In other words, a boundary is an extremity of any system beyond which it is not possible to find any part of that system (Varzi, 2004). Boundaries can be either naturally defined/intrinsic or observer designated (Dori et al., 2019). However, even naturally defined boundaries are observer-dependent. An observer can set the context of the system or define the boundary of the system using Ulrich's critical systems heuristics (Ulrich & Reynolds, 2010), group model-building techniques (Vennix, 1996), boundary adequacy tests (Sterman, 2000), or the experience of handling systemic problems.

Method

Morphological Analysis (MA) concerns the study of the structure and form of a physical object/conceptual entity (Zwicky, 1969). It enables a holistic representation of any physical/conceptual entity or system. MA focuses on classification and the derivation of meaning from the representation and, going further, even creating newer manifestations or extensions of the entity or system (Ritchey, 1998, 2011a). MA is fundamentally a technique that supports analysis-synthesis of physical and/or conceptual systems, in general. MA facilitates understanding of the whole-parts, or vice versa relationship, that is fundamental in the Systems Theory body of knowledge. MA comprehensively represents an entity in terms of what exists (reality), what could exist (possibilities), and what cannot too (impossibilities). The resulting Morphological Analysis Framework (MAF) is modular, scalable and adaptive. As and when any relevant body of knowledge is updated, the MAF can also be correspondingly updated.

MAFs can be constructed using different approaches. Yoon and Park (2005) used keyword analysis from patents to develop a MAF for technology forecasting. Veeravalli and Vijayalakshmi (2019) have used a systematic literature review and qualitative interviews to arrive at an enterprise social media literature MAF. MAFs can also be generated through a literature review followed by critical inquiry (Hall, 1989). Vijay Sunder et al. (2018) have used a combination of systematic literature review and classification frameworks to construct a MAF representation and a cross consistency matrix[3] for identifying research gaps of lean and six-sigma for services.

[3] We prefer the term 'variants' intersections matrix' to signify its actual purpose rather than the term 'consistency' that seems less appropriate.

In the MA of physical objects, the different, relevant physical characteristics and chemical properties of the whole object can become the dimensions and the respective, possible physical manifestations or values that they can take become variants (numerical and non-numerical). Thus, a 'whole' is represented in terms of its constituent 'parts', namely the dimensions and their variants, and their holistic integration. It is also possible to conduct a MA of conceptual aspects of physical objects. A simple illustration is provided in Appendix-1. The construction of MAFs for conceptual entities is possible following the identification of appropriate structural, conceptual, classification, and meta-morphological frameworks/models. In this paper, the SEC's conceptual model (Figure 1) provides the basis for its MAF representation. The MA approach is depicted in Figure 2.

INSERT FIGURE – 2 ABOUT HERE

A MAF representation of the SEC

The SEC's dimensions, viz., input, process, output, boundary, feedback, and anticipation, response and control unit, and their respective variants are discussed in this section.

Dimension: System Input

General Systems Theory, as discussed before, holds that inputs are integral components of the SEC but external to a system. This section has classified and characterised systems' inputs based on their types, temporal and dynamic nature, periodicity, and duration of application (see Figure 3).

Sub Dimension: Types of Inputs

Matter (tangible) or non-matter (intangible) are the fundamental inputs in terms of their material content. Food consumed by human beings is a matter-input, whereas the perception of the food's colour and presentation is a non-matter input. Considering the resource-based view of inputs proposed by Barney and Arikan (2001), matter-inputs can be further classified into human resources, natural resources, and material resources (man-made resources), including technologies and some built systems (infrastructure). Non-matter inputs can be classified into data/ information/ knowledge, financial resources, and networks/relationships. Technological resources and financial resources can be in the form of either matter or non-matter inputs.

Sub Dimension: Temporal Nature of Inputs

A system can receive both planned and unplanned inputs from its environment. Planned inputs are pre-decided or predicted inputs to the system, including each input's corresponding temporal schedules. Unplanned inputs could be ad hoc or even random. Periodic stock replenishment in an inventory management system is an example of a planned input to the system. Unplanned inputs are unanticipated by the system and could either be desirable or undesirable. For instance, an earthquake followed by a tsunami affecting the entire port operations is an unplanned input to the port system. Although the port authorities may be aware of or even estimate such an event's risk, its occurrence and consequences are unpredictable. The absence/non-availability of planned inputs can be considered unplanned inputs.

Sub Dimension: Dynamic Nature of Inputs

This dimension is characterised by the variations in the quantum of a specific input received by the system. The amount of stock replenished in an inventory management system need not be constant always. It depends on various factors such as demand, capacity, and contingencies and is usually planned to optimise the relevant costs. In contrast, the amount of rainfall a locality receives every year is a variable input but cannot be planned. The nature of the corresponding variations could either be linear or non-linear. Inputs can be constant, too; for instance, the power received by a machine to operate under stated conditions can be practically considered constant.

Sub Dimension: Duration of Application of Inputs

The duration of the application of input to the system is characterised by the pattern of provision of input from the system's inception/birth to its decommissioning/death, i.e., its life cycle. The variants of this sub-dimension are:

a) *permanent* – an input is available to the system throughout its lifetime; e.g.., sunlight as an input to the earth system,

b) *intermittent* – an input is available throughout the lifetime of the system but follows certain patterns that may not be continuous or predictable; e.g., rainfall on earth, and

c) *temporary* – an input is available to the system; however, it neither follows a pattern nor is necessary or guaranteed throughout its lifetime; e.g., consuming medicines by a temporarily sick person. One-off inputs to the system also fall under this category.

Sub Dimension: Periodicity of Inputs

The periodicity of inputs is characterised by their discrete or continuous nature of occurrence in a given period. The duration of application of inputs refers to each episode of input provision and should not be confused with their periodicity, which is examined across episodes. The flow of river water into a dam (water management system) is an example of a continuous input into a system, whereas each bite of a pizza during lunch is an example of a discrete input of food intake.

Sub Dimension: Controllability of Inputs

Inputs can be (a) controllable or (b) uncontrollable by the system/user of the system (Montgomery, 2017). For example, when a bicycle is pedalled, the pedalling force is an observable, limited, and controllable input, whereas the head and tailwinds are uncontrollable by the rider. Any open system could be subjected to uncontrollable inputs. For each additional uncontrollable input to a system, the risk of bad surprises increases significantly. Tomlinson and Dyson (1983) argue that in competitive markets, which are human activity systems, uncontrollable inputs are not completely independent of controllable inputs and vice versa. Typically, controllable inputs are pulled by the system from its environment, and the environment pushes uncontrollable inputs into the system.

INSERT FIGURE – 3 ABOUT HERE

Dimension: System Boundary

The boundary is an entity that separates a system from its environment; in physical systems, a boundary is usually perceptible. Boundaries can also be sharp/precise or fuzzy/vague, even in physical systems. A system could have multiple boundaries[4]. Philosophically, the boundary debate is an ongoing issue. Various philosophers have discussed the importance of the boundary conundrum (Tambassi, 2017; Varzi, 2001) – Does the boundary belong to the system, or the environment, or both, or neither? Here, we consider boundaries controlled by the system's ARCU. The classification and characterization of system boundaries given in Figure 3 open up a different perspective on the role of the boundary in the SEC.

[4] A physical system, such as natural systems and designed physical systems, will necessarily have one physical boundary and may have multiple conceptual boundaries. A conceptual system, such as a designed abstract system, will have at least one conceptual boundary.

Sub-dimension: Type of Boundaries

Based on the matter, system boundaries can be classified as (a) physical and (b) conceptual.

Physical Boundary

Physical boundaries are further classified into (i) spatial and (ii) temporal boundaries. The external profile of a designed physical system marks its spatial boundary, which demarcates the places in which human activities are performed (Ollier-Malaterre et al., 2019). However, in natural systems and human activity systems, spatial boundaries can be defined both naturally and artificially (Dori et al., 2019). For instance, a national park's boundaries can be geo-spatially or topographically mapped by the park authorities. They can also be defined by the natural variations in the physical, chemical, and biological properties between a national park and its environment. Temporal boundaries are relevant specifically to human activity systems such as events and games (Prasopoulou et al., 2006). A game has definite temporal boundaries, its start and end times. Any activity beyond the temporal boundary does not constitute the event or the game. However, some relevant actions could be performed both before and after an event or game.

Conceptual Boundary

Conceptual boundaries are designated by the observer and are non-physical. They can be classified as (i) contextual, (ii) notional, and (iii) relational boundaries. Contextual boundaries are specific to and defined by particular contexts. They predominantly concern activity systems and abstract systems. Cultural and economic boundaries fall into the category of contextual boundaries. As far as abstract systems such as languages are concerned, the grammar, syntax, and symbols help define the boundaries of the respective languages. For instance, the rules and syntaxes that apply to the English language need not apply to Sanskrit, Hebrew, or Chinese. Notional boundaries are only assumed and do not have physical manifestations (Churchill et al., 2004). They exist as spaces between buildings or between two machines in factory sites (Pau et al., 2019). Relational boundaries are defined by the nature of relationships between a system and its environment. They predominantly apply to activity systems (Benmore, 2016; Ollier-Malaterre et al., 2019). For instance, firms have defined roles and responsibilities for their stakeholders, such as employees, that define the stakeholders' relational boundaries. A marketing manager is related to a sales manager in terms of the respective roles and responsibilities. However, they are different entities (systems) within their firm.

Sub-dimension: Characteristics of Boundaries

System boundaries can be characterised in terms of their (a) rigidity, (b) permeability, (c) fuzziness, (d) perceptibility, and (e) responsiveness. Of these, responsiveness is a second-order characteristic, represented by the changes of state of the first four. However, these terms seem to be conflated in the literature. For instance, while explaining the cross-cultural interactions between the USA and Israel, Shamir and Melnik (2002) proposed that boundary rigidity and permeability are opposites. However, rigid boundaries can also be permeable. For example, the cemented brick walls of a building are rigid but could be permeable since water can seep through them. Similarly, there is confusion between the use of terms rigidity and fuzziness in geographical systems literature (Gleditsch et al., 2006). We attempt to resolve these issues concerning boundary characteristics via Table 2, which summarises the definitions.

INSERT TABLE – 2 ABOUT HERE

Sub-dimension: Functions of the Boundary

Strayer et al. (2003) have discussed and classified the functions of ecological systems' boundaries also applicable to general systems. These functions pose an epistemic challenge requiring the observer to designate a system boundary consciously; else, the functions cannot be ascribed to the system. Boundary functions include maintenance of the integrity of the system and assistance in realising systemic goals. Figure 4 elucidates Strayer's classification and the functions of the boundary concerning the system-environment interactions.

INSERT FIGURE – 4 ABOUT HERE

Dimension: System Process

System processes are performed to transform or convert inputs into outputs while following certain defined conditions, laws and rules (Skyttner, 2005). Processes can be natural (e.g., photosynthesis), human-designed (e.g., fractional distillation), or hybrid (e.g., fermentation of beverages). The type of system processes indicates the type of system. For instance, a virgin natural system becomes a human-activity system following the introduction of human-designed processes. The following section classifies and characterises system processes (See: Figure 3).

Sub Dimension: Process Structure

Process structure can be characterised and classified in terms of:

a) the input-output relationships across the system boundary – typically, black-box analyses of systems are based on this notion (Kasianiuk, 2016; Kimura et al., 2011), and
b) the observability of the system parts and their dynamic interactions – this can be seen in many cut-models of engineered systems and also in visual simulation models.

System processes can be (a) deterministic, (b) partially deterministic, or (c) non-deterministic. The system structure is one of the indicators of the nature of input-output relationships. If the system process is deterministic, then the outputs (and their variations) can be fully explained by the inputs (and their variations) after accounting for the uncontrolled inputs. For example, by measuring the pedalling force (a controlled input) applied to the bicycle, its speed (say, kilometres per hour) over a specific distance can be estimated, or even determined, accurately (within statistical limits) while being aware of uncontrolled inputs such as road bumps, gusts in different directions relative to the bicycle and its rider, and traffic conditions. In partially deterministic processes, knowledge of inputs can only partially explain outputs. Processes of human activity systems such as business organisations and governments are partially deterministic. Often, such systems involve human decision-making and participation within the process structure and exhibit adaptive behaviour due to dynamic, internal structural changes. For example, a business organisation can be certain about the controllable inputs (such as working capital, labour, and materials) that go into the business process. However, dynamic-uncontrollable inputs, such as demand, government policies, breakdowns in logistics systems, and weather, cannot be known a priori completely. Such inputs affect the business processes and the predictability of the outputs. In the case of non-deterministic or probabilistic processes, the output cannot be predicted using knowledge of only the inputs. An example is "non-deterministic, algorithmic abstract systems that generate random numbers".

Sub Dimension: Input-Output Conversion Arrangements

The input-output conversion arrangement is context-dependent. Clearly distinguishing the system from its environment is necessary to identify the type of conversion sequence correctly. Independent of the number of inputs to a particular process, the output must necessarily be singular. Based on the simultaneity of the input-output conversion, processes can be (a) sequential-linear, (b) sequential-circular, (c) parallel, or (d) networked (both sequential and parallel), as shown in Figure 5.

INSERT FIGURE – 5 ABOUT HERE

Sub Dimension: Process Recurrence

System processes can be recurrent as (a) single pass or (b) iterative during the input-output conversion. If the system inputs are subject to a particular process only once during their conversion into outputs, the process is classified as a single-pass process. Ideally, assembly lines involve a single-pass process. If inputs are subject to a particular process more than once but not necessarily regularly during the conversion, the process is iterative. Optimisation processes in operations research problem solving, system design and evaluation are generally iterative.

Sub Dimension: Production Process of the System

The production process of systems can be (a) autopoietic or (b) allopoietic. Autopoiesis (auto – self, poiesis – creation) is a process by which an organisation reproduces itself. An autopoietic process is an organisationally closed process defined by the system and not by its environment. It can occur in both (a) physical – e.g., biological cells (Varela et al., 1974b), and (b) non-physical systems – e.g., social systems with communication as the autopoietic unity (Luhmann, 1986), and corporations (Maula, 2006). Allopoiesis is a process by which an organisation produces something other than itself (e.g., any industrial production process).

Sub Dimension: Process Control

Process control in systems comprises (a) controlled, (b) partially controlled, or (c) uncontrolled processes, which are related to process variability. If the process variability is high, the process could be unstable and uncontrolled, whereas if the variability is low or constant, the process is stable and controlled (Nagrath, 2006). Process structure influences process control – deterministic processes involve better process control than non-deterministic ones. Process control focuses on the dominant variable, which explains the majority of the variations in a process. The control on the dominant variable could be based on managing (a) set-up, (b) time, (c) system component, (d) people, and (e) information (Juran & De Feo, 2010). A process may be controllable but could have been left uncontrolled. For example, a customer service process in a bank can be temporally controlled in various ways, such as setting a time limit for transactions, but the bank may not choose to do that. A process may not be controlled because the designer of the system may have overlooked a certain attribute of the process/input (e.g., the Cane Toad problem in Australia happened due to the overlooking of their breeding rate).

Sub Dimension: Process Inertia

Process inertia refers to the resistance of a process to change its rate, state, or function when induced by external forces or when a system warrants change. Process inertia has been discussed in the contexts of safety engineering (Kase & Wiese, 1987; Liang et al., 2018), process control (Andreev & Parsunkin, 2016; Demidovich et al., 2019), and management (Rumelt, 1995). Process inertia can be measured as the delay between the command to state/rate/function change and the actual change. It can also be measured by the efforts needed to respond to the command of the system's ARCU. In terms of inertia, processes can be (a) high-inertia or (b) low-inertia processes. The controlled nuclear fission process in power plants is a high-inertia process in which a shutdown (seizure of radioactivity) can take several minutes after the control rods are inserted. Processes in bureaucratic and high power-distance systems are generally high-inertia processes. The flow of electricity into appliances can be treated as a low-inertia process as it can be shut down instantaneously. In physical systems, the presence of accumulators or stocks and safety mechanisms increases process inertia. In human-designed systems such as businesses and sports teams, the organisation's attitude, culture, and mindset can drive process inertia in both directions.

Organisations with an innovative culture and risk-taking attitude generally have low process inertia.

Dimension: System Output

Purposive or purposeful systems strive to pursue their stated or ascribed purposes by operationalising and measuring their outputs concerning the goals or desired states of those systems set from time to time. System outputs are characterized based on their functional consequence and the nature of their delivery (see Figure 3), and also, similar to inputs, based on their (i) temporal nature, (ii) dynamic nature, (iii) periodicity, and (iv) controllability.

Sub-dimension: Functional Consequence

This represents the most fundamental output of a system. The system's purpose is to perform one or more designed or natural functions. For example, the primal purpose of survival is pursued by humans by performing a combination of various functions, viz., (i) maintenance (air, water, and food intake, and rest/sleep), (ii) regulation (pH, body temperature), (iii) conversion (food into energy), (iv) creation (of cells), (v) defence against and destruction of harmful foreign particles. Human activity systems such as business organisations also have multiple goals, including the organisation's growth, increasing the top line, and reducing the cost of goods sold. Some systems (e.g., thermostats) are designed to perform single functions (maintenance of temperature inside an enclosed space). Certain human activity systems are also designed to perform functions such as discovery (e.g., R&D and simulation systems), standardisation (ISO systems), and characterisation (morphological analysis).

Sub-dimension: Temporal Mode of Output Delivery

The output of a system can be (a) one-off, (b) intermittent–probabilistic, (c) intermittent–deterministic, or (d) continuous, based on the temporal mode of the delivery. An output delivered only once in the system's lifecycle is classified as 'one-off'. For example, the thrust and flight provided by a rocket propulsion system are one-off. If a system can deliver output intermittently by design and its occurrence does not follow any temporal pattern, it is an intermittent–probabilistic type of output. For example, a drinking water dispenser delivering water to users, who arrive randomly.

The system delivers the intermittent–deterministic type of output by following a temporal sequence known to the system designer. For example, the functioning of an automated traffic control system or the chiming of a musical clock. The output is continuous if a system delivers output continuously as long as it receives input. The electric bulbs in a household provide light as long as electric power is continuously provided.

Dimension: Feedback

Feedback units can be designed to process information from the inputs, processes or outputs. Since feedback is a distinctive type of input into the system, the characteristics discussed under the system inputs, viz., temporal nature, dynamic nature, and periodicity, also apply to the feedback. Also, commonly feedback is considered as positive or negative depending upon its amplifying or regulating effects on the output. Such common considerations of feedback are represented in the MAF but are not discussed below. The types of system feedback collection and transmission (see Figure 3) are discussed here. Feedback Collection can be studied in terms of the methods, modes, sample size, and feedback measurement.

Sub-dimension: Methods of Feedback Collection

Feedback collection methods influence feedback quality and cost of collection. They include (a) manual, (b) mixed-mode, or (c) automatic collection. When feedback is obtained from the system's output/input/processor only through human efforts, it is manual feedback (for example, customer satisfaction interviews). Such feedback is prone to various biases. Mixed-mode feedback collection involves supporting devices and human beings, while automatic feedback is collected completely through a device programmed specifically to collect feedback (e.g., water level indicators). Since the classifications under the feedback collection method are also applicable to feedback transmission methods to the ARCU, they are not discussed separately.

Sub-dimension: Temporal mode of feedback collection

Feedback may be collected from the output/input either (a) continuously or (b) intermittently. In the case of continuous feedback, the temporal gap between successive feedback instances is negligibly small. Continuous feedback is collected when the system's output is a critical variable, in which any deviation beyond set tolerance limits may become wasteful or damaging. For example, the steam pressure indicator in a boiler continuously indicates the boiler drum's pressure and is crucial for the boiler's safety.

Feedback collected intermittently involves a temporally perceptible/measurable period between any two successive feedback instances. It can further be classified into (a) intermittent-random and (b) intermittent-systematic. When the feedback is collected intermittently and in no particular order or logic, it is intermittent-random feedback collection. The randomised selection of finished goods for destructive testing serves as a good example. When the feedback is collected intermittently, and some logic of selecting a feedback sample is present, it is intermittent-systematic. The recruitment of every fifth person for a feedback survey serves as an example.

Sub-dimension: Sample-size of feedback collection

Feedback may be collected from the whole of the output/input or only partially. When the feedback is collected for all the system outputs/inputs, it is termed the census. Alternatively, if it is restricted to only a certain percentage (say 10 to 20%) of the output/input, it can be termed as quota feedback collection. Feedback collected randomly with no lower or upper limit set by the observer/controller on the number of feedback samples is random sample-sized.

Sub-dimension: Feedback Measurement

In closed systems, feedback units may be commissioned to measure (a) the output/input attributes and (b) deviations from the expected output/input. A feedback unit collects data on the attributes of the outputs/inputs and converts them into actionable information. For example, the water level in a dam is an attribute of the output of the dam system's operation. A feedback unit can also simultaneously measure multiple attributes of the system output. A master health check-up is a type of feedback that measures the presence (and absence) of deviation of body parameters such as blood glucose level, LDL and HDL cholesterol levels in the body. This type of feedback falls into the second category, which measures the deviations from the expected output crucial for course corrections.

Sub-dimension: Feedback Transmission

The collected feedback is processed into actionable information or sometimes sent as raw data/information to the ARCU. The feedback unit may choose to or be programmed to identify and filter urgent from ordinary information for immediate action. Based on temporal considerations, the feedback sent to the ARCU can be classified as (a) immediate transmission and (b) delayed transmission. When the temporal gap between feedback collection and transmission is negligible, it is immediate. For example, a vehicle's speed at a given time gets transmitted immediately to the governor's electronic control unit. When the temporal gap between collection and transmission is discernible, it is delayed. Sometimes, feedback collection requires certain processing before transmission to the ARCU. Feedback collection from many customers is an example since it will require consolidation and analysis before a response is initiated.

Dimension: Anticipation, Response, and Control

As the nomenclature suggests, the primary function of the system ARCU is to respond to the feedback and control the inputs to and the outputs of the system. The ARCU's function includes anticipating or sense-making of the attributes of the environment. However, not all systems would be equipped with an anticipation unit. The ARCU may be lumped or distributed across multiple locations inside a system. The morphology of the ARCU's activities, in terms of sub-dimensions and variants, is presented in Figure 3.

Sub-dimension: Response Time Frame

An ARCU can respond to the feedback in two different modes, viz., (a) instant or quick response, and (b) delayed response. The responses depend on the importance of the input/feedback, the urgency of the required action, and the availability of resources to address the issue. There may not be any response from the system if resources for response and control would not be available, and the feedback would not be crucial. If the feedback is crucial and needed immediately, the system will prioritise this event and override other responses despite resources unavailability.

Sub-dimension: Response and Control Strategy

The system may be homeostatic or robust-resilient to external perturbations or adapt to the environment to fulfil its purpose due to its ARCU. The system's strategies directed by the ARCU depend on factors such as frequency of perturbation (Low to High), the intensity of the perturbation (Low to High), the difficulty of adaptation, type of the system, the nature of the system (Passive to Active), and the ARCU's ability to deal with a variety of inputs. The system's strategies are formulated in terms of its Resilience (Helfgott, 2018; Herrera, 2017), Robustness (Jackson, 2016), and Adaptation (Holland, 1992) properties. We term the two resulting strategies as 'robust-resilient' and 'adaptive'. The institutionalisation of adaptive strategies into the system improves its resilience and robustness. A system may employ the robust-resilient or adaptive simultaneously, sequentially, or in any order depending on various factors such as goal (output), input, feedback, and systems processes.

Robust-Resilient Strategies

If a system is designed to maintain its key characteristics by being highly robust and resilient and having the bandwidth to accommodate perturbations from the environment, it may not respond to all changes in the inputs or the aberrations in the outputs notified through feedback. For example, Due to their inherent robustness, autopoietic systems may choose not to respond to environmental changes. However, such systems are precarious and risk failure (Valentinov, 2017a, 2019).

Adaptative Strategies

The system ARCU can modify either the quantum of input to the system or the system's structure to adapt to external perturbations. Such modifications are called adaptive strategies (Levins, 1968), which can be classified as (a) structural, (b) behavioural, or (c) input/output modification. An example of input modification is a cinema ticket booking system stopping the sale of tickets when the hall is booked fully. An automobile assembly line can increase the input rates of various parts to increase the outputs based on the demand from the market.

A system can structurally adapt itself to its environment through four means:

a) by structurally modifying itself either by adding or deleting elements. E.g., Human beings wearing spectacles for improved vision.
b) by changing – adding, deleting, or reconfiguring – the interrelationships among its elements. E.g., changing of field positions and roles in a football team.
c) by altering the capacity of individual elements by reconfiguring their physical or conceptual attributes. E.g., increasing the RAM capacity in the CPU of a computer.
d) by metamorphosis – it is a stage-based purposeful process of changing the system's form to adapt to its environment. Metamorphosis can also be a combination of previously discussed structural modification strategies.

A system may also modify its behaviour to adapt to its environment without structurally changing itself. While suddenly exposed to a cold environment, human beings shiver to keep their bodies warm. However, such macro-level behaviour modifications can be observed to be temporary. Human beings would not continue to do so and may have to resort to a permanent structural solution in the form of getting a blanket or putting on warm clothing. Systems may also modify the (i) rate of flow of input/output, (ii) totally shut off certain types of input/output temporarily, or (iii) add/remove an input/output by responding to the environment.

Sub-dimension: Duration of Application of Response and Control

The nature and application of a system's response and control can be classified as (a) temporary or (b) permanent. The response may involve structural, behavioural, or input/output modifications. Humans shivering in the cold is a temporary behavioural modification, whereas placing a barricade to control traffic flow on the road is a temporary structural modification. The cinema-hall ticket booking situation presented above is an example of a temporary input modification. It is acknowledged that the structure and behaviour in any system go hand in hand,

and changes in them are complementary. It may not be possible to have permanent behavioural modifications without necessary structural modifications. Building a dam to restrict or divert water flow is an example of an intentionally permanent structural modification.

Discussion

The MAF representation is useful in characterising the SEC's components, viz., inputs, outputs, boundary, feedback, anticipation, response, and control unit.

Characterisation

The MAF representation comprises six dimensions, with each having at least two sub-dimensions. The number of unique possible combinations across the dimensions can be determined as presented in Table 3. The product of the elements of the variants' set of each characteristic sub-dimension (see column 2) is the total number of its mutually exclusive manifestations (see column 4), including the possible and impossible ones as well. For example, a "rigid" and concurrently "fuzzy" boundary, or a "maintenance" functional consequence of output and "one-off" output delivery are impossible manifestations. Although Table 3 indicates the upper limit of characterisation possibilities, MAF users may use only those dimensions and sub-dimensions they consider appropriate.

INSERT TABLE – 3 ABOUT HERE

The MAF representation of SECs offers the following benefits:

a) Identifying research opportunities in the literature (in General Systems Theory and its applications in specific contexts) worthy of research attention (Ritchey, 2005; Sunder et al., 2018).

b) basic principles for systems design and evaluation (Bahill & Botta, 2008; Churchman, 1971). Practitioners can use the characterisation to design or upgrade systems of interest.

These are elaborated below.

Literature Gaps identified through the 'Variants' Intersection Matrix (VIM)

If sD_i (i = 1 to n) denotes the characteristic sub-dimensions in the MAF, then n = 30 according to the previous section. Let V_{ij} (j = 1 to k) be the number of elements in the variants' set constituting sD_i. Then the total number of possible combinatorial configurations (T) is denoted by

$$T = \prod_{i=1;\, j=1}^{n;\, k} V_{ij}$$

Based on the MAF representation, a total of 7.80 X 10^{13} combinations are possible. However, such a massive set of combinatorial configurations would be overwhelming and practically impossible to process. Hence, a possible pairwise combination of variants (Ritchey, 2011b), determined using the equation below, is constructed first, where N is the total number of variants and T_2 is the total number of possible dyadic combinations represented in a VIM.

$$T_2 = \frac{1}{2} N \,(N - 1)$$

The complete VIM presents a tabular representation of the possible pairwise associations among the variants. All the variants in the MAF representation are presented on both axes. In this case, as the total number of variants N is 101, this VIM indicates a total number of 5050 possible pairwise combinations. The VIM can be used to indicate research opportunities visually. Here, we have not depicted the complete VIM with all possible pairwise combinations. However, to help identify research opportunities, we present Figure 6. A maximum of 132 research opportunities can be identified using this illustrative VIM. However, only a sub-set of possibilities may be attractive enough since (i) a logical relationship between two variants may not exist, (ii) the relationship between two variants may be trivial, or (iii) the relationship could have been well studied already. The identified opportunities after excluding the cases mentioned above can be evaluated for their research attractiveness and value. Systems research can be (a) application based, i.e., researches using a systems approach, or (b) theoretical, or researches on the nature of the system (Hammond, 2017). It is left to the researchers' creativity and imagination to frame research questions based on these identified opportunities and a thorough literature review on the identified opportunities.

INSERT FIGURE – 6 ABOUT HERE

The VIM represented in Figure 6 contains variants of ARCU across the x-axis (ARCU) and Input across the y-axis (Input). The pairwise combinations are then assessed to determine if attractive research opportunities exist. The following two principles help identify research opportunities: (a) the possibility of structural or functional connections and (b) conceptual or contextual proximity of the two variants. Of the 132 combinations, at least 84 research opportunities are indicated. Appendix 2 presents a few examples of how each pairwise combination can be examined for research potential. Figure 6 also illustrates the availability of literature on some pairwise combinations in selected databases viz., Scopus, Web of Science, and IEEE Xplore. Research opportunities could not be found using only the individual variants constituting the "adaptive strategies". Hence, the variants belonging to the "adaptive strategies" sub-dimension were clubbed together, and then research opportunities could be found. The search terms used to identify literature are listed in Appendix 3.

System Design and Evaluation (SDE)

Since the idea of purpose is fundamental to all human-designed systems, the design and evaluation of their functioning/performance become crucial for their pursuit of purpose. Understanding the SEC's components is essential for designing and evaluating the system or altering the system design. Loose integration among the SEC's various components may result in unintended and undesired consequences to the system following its design. Based on the SEC's general MAF characterisation, we seek to initiate basic thinking about SECs and present four basic propositions concerning the system's design and evaluation.

1. *IF* the System could be/is susceptible to risks of uncontrollable inputs from its environment, or its environment could be/is susceptible to risks of uncontrollable outputs of the system, *THEN* the boundary of the system should be designed to be as non-permeable as will be feasible, or at least tightly controlled, to unknown inputs or outputs, as the case may be.
2. *IF* the inputs to the system or the system's outputs are continuous or non-linear, *THEN* the feedback collection from the environment should be designed to be continuous, and the feedback transmission should be designed to be immediate to lower the risk of bad surprises.
3. *IF* the system's process inertia is high, *THEN* (a) the system must employ immediate and continuous feedback by design, and (b) the system design must adopt the robust-resilient strategy.
4. *If the system's output* is designed to maintain the state of the system, *THEN* the deviation from the expected output must be monitored periodically. The feedback from unplanned and uncontrolled inputs should also be monitored to enable system adaptation.

These propositions concerning the system's survival and health, though only indicative and not exhaustive, point to the potential application of the SECs' characterisation and will have to be validated by rigorous research. Based on these propositions, several of the systems' aspects deserve research attention on a theoretical plane. For instance, beginning with purpose, the structural arrangements of the SECs' components, their interactions and influences on the systems' dynamic behaviour, and the systems' lifecycles and evolution could be researched. On the practical front, propositions such as those stated above deserve empirical evaluation using systemic action research (See: Ison, 2010; Wadsworth, 2011), which is also an intervention based cyclical process (Sankaran, 2017; Sankaran et al., 2009) that is at the heart of the SDE. These practices are essentially iterative exercises to sustain the required levels of systems' performance, including working for continuous performance improvement.

Conclusion

The SEC's conceptual and graphical model and its MAF representation containing a total of 30 sub-dimensions and 101 variants are novel contributions of this article. The structural arrangement of existing knowledge in systems theory, and the inclusion of the ARCU and some new sub-dimensions such as the characteristics of the system boundary, input-output conversion, feedback measurement, and response and control strategies are potentially useful contributions to systems theory and practice. The paper enables a fundamental understanding of SECs and their structural and functional dynamics in the context of an identified problem. The dimensions, sub-dimensions and variants can be examined and used to characterise any given SEC, systematic identification of possible literature gaps, and system design and evaluation. Although due care and diligence were taken during the conception and development of the MAF representation, its comprehensiveness should be ascertained. However, the MAF's modular nature facilitates incremental expansion by newer dimensions, sub-dimensions and variants that may be identified and yield more combinations of system manifestations. The MAF serves as a basis for systematic creativity in the physical, conceptual, and syncretic system manifestation domains.

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Tables

Table 1 – Functions of ARCU in various Systems

Martinelli's System Classification	**Functions of ARCU**		
	Control	**Response**	**Anticipation**
Non-System	No	No	No
Static	Yes	No	No
Simple Dynamic	Yes	May Be	No
Feedback Dynamic	Yes	Yes	No
Multilevel	Yes	Yes	May Be
Autopoietic	Yes	May Be	May Be
Adaptive	Yes	Yes	Yes
Evolutionary	Yes	Yes	Yes

Table 2 – Sub Dimension: Characteristics of Boundary		
Boundary Characteristics	**Definition**	**Examples**
Rigidity	(i) Internal and external perturbations will have little or no effect on rigid boundaries, i.e., the shape/form of the boundary will not change ordinarily. (ii) Flexible boundaries will exhibit changes in shape/form consequent to perturbations. They can be further classified into (a) fixed perimeter boundaries and (b) changing perimeter boundaries.	Rigid Boundaries – Automobiles, Buildings, etc. A country's political boundaries are ordinarily rigid. Flexible Boundaries – Activity systems generally have flexible boundaries. The layout of supermarkets is often changed depending on seasons, inflow, etc. The expanding boundary of a forest fire is an example of a changing perimeter boundary.
Permeability (Workman, 2005)	(i) Permeable boundaries will enable the transmission of physical and conceptual entities from the environment to the system and vice versa. (ii) Such transmissions will not be possible in the case of non-permeable boundaries. *However, boundaries can be selectively permeable. Boundaries can allow information but may not allow matter, to pass through.*	Permeable Boundaries – Semi-permeable membranes in the osmosis process, computer networks with security protocols. Non-Permeable Boundary – Boundaries of a vacuum flask, cleanrooms, and secret societies.
Fuzziness (Jacquez et al., 2000)	(i) Crisp boundaries separate a system from its environment sharply and precisely. (ii) Fuzzy boundaries are vague, imprecise or unclear.	Crisp Boundaries – In general, boundaries of designed physical systems are crisp. Political Boundaries are crisp. Fuzzy Boundaries – the influence of a leader on citizens, influence of one culture on others, and ecotones in natural ecosystems.
Perceptibility	(i) Boundaries that are either physically visible to or conceptually recognised by observers. (ii) Boundaries that are neither visible to nor recognised by observers.	All physical boundaries are visible. Contextual boundaries such as rules and syntaxes of a language are perceptible. An individual may not perceive racial stereotypes of another individual during interactions.
Responsiveness	(i) Responsive boundaries change their state (defined by characteristics mentioned above) due to endogenous or exogenous causes/factors. (ii) Non-responsive boundaries do not exhibit state changes due to endogenous or exogenous causes/factors. Responsiveness can be characterised by the adaptability and agility of the response.	A country's boundary, which is generally non-permeable, may become permeable to refugees. Non-responsive boundaries exist only in theory as boundaries change due to endogenous or exogenous factors. The nearest example is that of a boundary between two friendly countries.

Table 3 - Unique Possible characterisations of Components (Dimensions) of the SEC			
Components (Dimension) (1)	**No. of Characteristic Sub-dimensions; (Variants' Set) (2)**	**Total Variants (3)**	**No. of Unique Possible Characterisation (4)**
Input	6; (7,2,2,3,3,2)	19	504
Boundary	7; (5,3,2,2,2,2,6)	22	1440
Process	6; (3,4,2,2,3,2)	16	288
Output	2; (12,4)	16	48
Feedback	6; (2,2,3,3,3,2)	15	216
Anticipation, Response, and Control	3; (2,9,2)	13	36

Appendix

Appendix 1 – Illustrative Example of partial MA of Wrist Watch

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Meta-Dimension	**Dimension**	**Sub-Dimension**	**Variants**
Physical Aspects of Wrist Watch	Display Style		Digital
			Analog
			Hybrid
	Display Shape		Circle
			Square
			Rectangle
			Hexagonal
Conceptual Aspects of Wrist Watch	Performance	Accuracy	> 100 ms
			99 – 10 ms
			< 10 ms
		Battery Life	> 24 months
			12 – 24 months
			< 12 months

Appendix 2: Illustration of nature of the relationship of pairwise combinations of the VIM

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Pairwise Combination	**Possibility of Structural/ Functional Connection**	**Conceptual Proximity of the Combination**	**Relationship**	**Explanation**
Temporary Input **(vs)** Addition/ Deletion of a system member	Not Available	Proximal	There may be a logical relationship, but it is not directly discernible (?)	Structural modifications such as addition/deletion of a member are not necessary for temporary inputs. However, if the frequency of occurrence of the temporary input is high, a permanent structural modification may be used.
Uncontrolled Input **(vs)** Permanent Response	Not Available	Proximal		The system designers do not usually design response to uncontrolled inputs. However, the system may exhibit resilience towards uncontrolled inputs
Permanent Input **(vs)** Temporary Response	Not Available	Not Proximal	There is no logical relationship (N)	Assuming that the response is necessary only as long as the input is provided, any temporary response to a permanent input is also not logically tenable.

Appendix 3- Literature Search ARCU vs Inputs

Search Term Combinations (search conducted on 14-06-2020)	**IEEE Xplore**	**SCOPUS**	**WOS**	**Total***
(resilience OR robustness) AND ("plann* Input*")	92	171	40	217
(resilience OR robustness) AND ("unplann* Input*")	0	0	0	0
(resilience OR robustness) AND ("controll* Input*")	1151	1898	567	2537
(resilience OR robustness) AND ("uncontroll* Input*")	1	0	0	1
(resilience OR robustness) AND ("constant Input*")	32	43	24	71
(resilience OR robustness) AND ("variable Input*" OR "varying input*")	20	148	68	168
(resilience OR robustness) AND ("linear Input*")	20	48	12	64
(resilience OR robustness) AND ("non*linear Input*")	20	95	37	120
(resilience OR robustness) AND ("permanent Input*")	0	0	0	0
(resilience OR robustness) AND ("intermittent Input*")	2	5	1	5
(resilience OR robustness) AND ("temporary Input*")	0	0	0	0
(resilience OR robustness) AND ("transient Input*")	2	4	4	6
(resilience OR robustness) AND ("continu* Input*")	12	32	14	38
(resilience OR robustness) AND ("discrete Input*")	10	12	4	14
("adapta*" OR "adaptive strateg*") AND ("plann* Input*")	0	1	0	1
("adapta*" OR "adaptive strateg*") AND ("unplann* Input*")	0	0	0	0
("adapta*" OR "adaptive strateg*") AND ("controll* Input*")	28	11	29	52
("adapta*" OR "adaptive strateg*") AND ("uncontroll* Input*")	0	3	2	3
("adapta*" OR "adaptive strateg*") AND ("constant Input*")	19	40	2	50
("adapta*" OR "adaptive strateg*") AND ("variable Input*" OR "varying input*")	34	67	45	104
("adapta*" OR "adaptive strateg*") AND ("linear Input*")	27	43	14	55
("adapta*" OR "adaptive strateg*") AND ("non*linear Input*")	27	27	17	51
("adapta*" OR "adaptive strateg*") AND ("permanent Input*")	0	1	0	1
("adapta*" OR "adaptive strateg*") AND ("intermittent Input*")	0	2	2	2
("adapta*" OR "adaptive strateg*") AND ("temporary Input*")	0	0	0	0
("adapta*" OR "adaptive strateg*") AND ("transient Input*")	0	7	7	11
("adapta*" OR "adaptive strateg*") AND ("continu* Input*")	13	30	21	37
("adapta*" OR "adaptive strateg*") AND ("discrete Input*")	10	16	7	22
"permanent response" AND ("plann* Input*")	0	0	0	0
"permanent response"AND ("unplann* Input*")	0	0	0	0
"permanent response"AND ("controll* Input*")	0	0	0	0
"permanent response"AND ("uncontroll* Input*")	0	0	0	0
"permanent response"AND ("constant Input*")	1	0	0	1
"permanent response"AND ("variable Input*" OR "varying input*")	0	0	0	0
"permanent response"AND ("linear Input*")	0	0	0	0
"permanent response"AND ("non*linear Input*")	0	0	0	0
"permanent response"AND ("permanent Input*")	0	0	0	0
"permanent response"AND ("intermittent Input*")	0	0	0	0
"permanent response"AND ("temporary Input*")	0	0	0	0
"permanent response"AND ("transient Input*")	1	0	0	1
"permanent response"AND ("continu* Input*")	0	0	0	0
"permanent response"AND ("discrete Input*")	0	0	0	0
("transient response" OR "temporary response") AND ("plann* Input*")	0	0	0	0
("transient response" OR "temporary response") AND ("unplann* Input*")	0	0	0	0
("transient response" OR "temporary response") AND ("controll* Input*")	21	9	4	27
("transient response" OR "temporary response") AND ("uncontroll* Input*")	0	0	0	0
("transient response" OR "temporary response") AND ("constant Input*")	7	1	7	14
("transient response" OR "temporary response") AND ("variable Input*" OR "varying input*")]	7	23	5	31
("transient response" OR "temporary response") AND ("linear Input*")	3	5	2	5
("transient response" OR "temporary response") AND ("non*linear Input*")	7	4	0	11
("transient response" OR "temporary response") AND ("permanent Input*")	0	0	0	0
("transient response" OR "temporary response") AND ("intermittent Input*")	0	0	0	0
("transient response" OR "temporary response") AND ("temporary Input*")	0	0	0	0
("transient response" OR "temporary response") AND ("transient Input*")	14	22	4	35
("transient response" OR "temporary response") AND ("continu* Input*")	6	5	3	10
("transient response" OR "temporary response") AND ("discrete Input*")	2	0	0	2

*-excluding duplicates

Numbers in the table indicate articles – journal articles, conference articles, review, book chapters, and books in each of the databases.